PROCEEDINGS OF THE . . INSTITUTE OF BRITISH FOUNDRYMEN.

VOLUME XXV. 1931-1932.

Containing the Report of the Twenty-Ninth Annual Conference, held at Newcastle-upon-Tyne, June 8th, 9th, and 10th, 1932; and also Papers and Discussions presented at Branch Meetings held during the Session 1931-1932.

Institute of British Foundrymen.

Head Office:
Saint John Street Chambers, Deansgate, Manchester, 3.
(Registered Office: 49, Wellington Street, Strand, London, W.C.2.)

LONDON: Printed by
"THE FOUNDRY TRADE JOURNAL,"
49, Wellington Street, Strand, London, W.C.2.

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AWARDS 1931—32.

THE "OLIVER STUBBS" GOLD MEDAL.

1932 Award to Mr. J. E. HURST,

"for original work in the metallurgy of Cast Iron during the past year."

DIPLOMAS OF THE INSTITUTE

were awarded to—

Mr. T. R. TWIGGER, for his Paper on "Some Recent Developments in Automobile Cast Irons," given before the Birmingham Branch.

Mr. W. WEST, for his Paper on "Low Total-Carbon Cast Irons and their Service to the Foundry Industry," given before the Lancashire Branch.

Dr. GUIDO VANZETTI, for his Paper on "The Italian Foundry Industry," given before the London and Lancashire Branches.

Mr. W. Y. BUCHANAN, for his Paper on "Sand Testing in the Foundry," given before the Scottish Branch.

Dr. H. W. SWIFT, for his Paper on "Modern Practice in Cast Iron Testing," given before the West Riding of Yorkshire Branch.

THE BUCHANAN SILVER MEDAL.

1932 Award.

Mr. J. HOLMES, Lancashire Branch Junior Section.

THE OLIVER STUBBS MEDAL.

The Oliver Stubbs Medal has been awarded as follows:—

1922.—F. J. Cook, M.I.Mech.E.

1923.—W. H. Sherburn.

1924.—John Shaw.

1925.—A. Campion, F.I.C.

1926.—A. R. Bartlett.

1927.—Professor Thomas Turner, M.Sc.

1928.—J. W. Donaldson, D.Sc.

1929.—Wesley Lambert, C.B.E.

1930.—James Ellis.

1931.—John Cameron, J.P.

1932.—J. E. Hurst.

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The Institute of British Foundrymen.

TWENTY-NINTH ANNUAL CONFERENCE, NEWCASTLE-UPON-TYNE.

JUNE 7, 8, 9 and 10, 1932.

The 29th Annual Conference of the Institute of British Foundrymen, held at Newcastle-upon-Tyne from June 7 to 10, under the Presidency of Mr. Victor Stobie, M.I.E.E. (of the Stobie Steel Company), was most successful throughout, both from the instructional and the social points of view, and the Newcastle Branch worthily maintained the reputation it established as host in 1924, when the Institute's annual conference was last held in that city. In addition to the technical meetings, many visits were arranged to various heavy engineering works which abound in this area, and the civic, industrial and educational authorities combined with the Newcastle Branch in the arrangement of the many social functions which the Institute's members and their ladies enjoyed. A special ladies' programme was arranged, as on previous occasions. Hearty thanks were expressed by all to the Executive Committee at Newcastle, which consisted of Mr. C. Gresty (Chairman), Mr. A. Logan, Mr. W. Scott, Mr. R. J. Shaw (hon. treasurer) and Mr. J. W. Eckford (hon. secretary); and to the Ladies' Committee, consisting of Mrs. S. E. Dawson, Mrs. J. W. Eckford, Mrs. A. Logan and Mrs. W. Scott.

A Civic Welcome.

The members and their ladies assembled on Wednesday morning, June 8, in the lecture theatre of the Literary and Philosophical Society, when a welcome was extended to them by representatives of the civic, industrial and educational interests of the district, in the persons of the Deputy Lord Mayor of Newcastle (Councillor J. Crosby), the Sheriff of Newcastle (Councillor J. Leadbitter), Sir Arthur Sutherland (representing the Rt. Hon. Lord Joicey, J.P., the President of the Newcastle and Gateshead Incorporated Chamber of Commerce), and Sir William Marris, K.C.S.I., K.C.I.E., B.A., D.Litt. (Principal of Armstrong College, Newcastle, and Vice-Chancellor of the University of Durham).

These gentlemen were introduced by Mr. A. Harley, the retiring President of the Institute, who recalled the very happy conference which was held in Newcastle in 1924, and said that all the members were glad of the opportunity to visit the city again. He regretted that trade was not so good as it ought to be, but was of opinion that the tide was on the turn and felt sure that Newcastle and district would be in the forefront of the coming trade revival.

The Deputy Lord Mayor first conveyed the apologies of the Lord Mayor of Newcastle (Councillor J. G. Nixon, J.P.), who had intended personally to welcome the visitors, but had had to travel to Ireland to attend to business matters. Newcastle (continued the Deputy Lord Mayor) was honoured by the fact that the Institute had chosen it as a suitable place in which to hold this annual conference. He appreciated that it was always difficult to choose the most suitable place for any conference, and Newcastle was sincerely honoured by the choice which had been exercised on this occasion by a body so important as the Institute of British Foundrymen. This conference was not merely of a national, but an international, character, and he expressed the hope that the Institute's

deliberations would be helpful in every possible way. He personally had had a little experience of both national and international organisations set up for purposes such as the Institute had in view, and as a result of that experience he could say quite definitely that such association was of inestimable value in the improvement of the technique of an industry and in every way. The founding industry was basic to the great industries which had made Newcastle-upon-Tyne famous. If the work in the foundry were not well and truly done there was trouble later on all along the line.

The Deputy Lord Mayor expressed the hope that in connection with educational work the conference would be particularly and materially successful. He hoped also that the members would not overlook the value of the social functions, to which the city of Newcastle hoped to make its contribution. All work and no play made Jack a dull boy, and he was glad, therefore, that a little time was to be spared for play during the period of the conference.

Finally, the Deputy Lord Mayor extended a welcome to the ladies attending the conference, and assured them that they would find much of interest in the beautiful and interesting places situated around the city of Newcastle, and in the fine shops within the city.

Local Foundry Celebrities.

The Sheriff of Newcastle (Councillor J. Leadbitter), supporting the cordial welcome extended by the Deputy Lord Mayor, said that but for coal and metals, the ancient city of Newcastle would not be what it is to-day. Unfortunately, trade was not good on Tyneside at the moment, but he expressed the hope that as the result of the deliberations at this conference some schemes would be formulated which would help the great industries not only of Tyneside but of the whole British Isles. His attendance at this meeting reminded him of two interesting facts. One was that a great friend of his in his young days was a working moulder,

employed within a stone's throw of the building in which this meeting was being held, who had subsequently risen to great heights in the political world. It was Mr. Arthur Henderson, ex-Foreign Secretary (applause), who had contributed something towards the progress of the founding industry when employed as a journeyman in Messrs. Stephenson's foundry in South Street, Newcastle. Mr. Henderson was a Scotsman, possessing the Scottish tenacity and perseverance, and it was to that, in addition to his native ability, that one could attribute his achievements as a member of the British Government. The second fact to which the Sheriff referred was that when last he had attended a meeting in the lecture hall of the Literary and Philosophical Society it was for the purpose of hearing a lecture on steel, by an intimate friend of his, Professor Turner, of Birmingham. He was afraid, however, that he was very little wiser at the end of the lecture than at the beginning, because the materials which he had to mould were much more plastic than steel. (Laughter.)

Finally, he expressed the hope that the members of the Institute would derive much profit from their deliberations, and much pleasure from the social functions which had been arranged.

Sir Arthur Sutherland, after expressing regret that Lord Joicey was unable to attend the meeting, extended to the Institute a cordial welcome on behalf of the industries of the district. He was afraid that the industries were passing through a depression which was world prevalent, but he pointed out that all stones, whether atmospheric or commercial, would rock themselves to rest, and expressed the hope that very soon we should see through the clouds some signs that the sunshine of prosperity would again shine upon us. In a reference to the excursions which the members were to make from Newcastle, Sir Arthur reminded the members that they were to visit Hadrian's Wall. In olden days, he said, there were stupid people who built walls

to keep the Scotsmen out; nowadays, however, they were building railroads and motor roads in order to bring them in, because they were very valuable to the district, and for many years the industries there had been manned by Scotsmen.

An Industrial Survey.

Sir William Marris, K.C.S.I., K.C.I.E., B.A., D.Litt., said that as Vice-Chancellor of the University of Durham and Principal of Armstrong College, Newcastle, he was glad of the privilege of joining in the expressions of welcome. The University, he said, was the university of a great industrial area, and Armstrong College in particular was concerned with many matters of interest to the great basic industries on which the prosperity of this part of the country rested. There were at the College big departments, such as those of civil, mechanical, marine and electrical engineering, and naval architecture, concerned with matters of great moment to the heavy industries, and, therefore, to the interests which the Institute of British Foundrymen represented. The College authorities were doing their utmost to help those interests, both by turning out students thoroughly well qualified to play their part in industry and by researches conducted by experts in the various departments, the results of which researches had been proved from time to time to be of material value to industry. They were anxious to do all they could to contribute to the recovery of prosperity to which all looked forward. Their interests were very much those of industry itself; when industry was in a bad way, then they were in a bad way, relatively speaking, and no one would rejoice more than they when the position improved.

A particular matter in regard to which the College had endeavoured to manifest its value and interest to industry was that of the industrial survey of the heavy industries of this part of the country. It had been undertaken by Armstrong College at the request of the Government, and he hoped that the results would be

made public shortly. To his mind, there had been regrettable delay in the printing and publication of the report; that was not the fault of the College, because the matter was taken out of their hands by the Government some time ago, but it was expected that the report would appear shortly, and he believed that in its pages there would be found a useful and sympathetic study of many matters which would be of interest to members of the Institute. During the forthcoming session at the College it was hoped to arrange for the delivery of a series of lectures by experts on particular points of interest emerging from the report. Finally, Sir William echoed the hope that the deliberations at the conference would be most valuable and profitable.

Presentation of Oliver Stubbs Gold Medal.

The RETIRING PRESIDENT then invited the Deputy Lord Mayor to present the Oliver Stubbs Gold Medal—the premier award of the Institute—to Mr. J. E. Hurst, in recognition of his outstanding contributions to the metallurgy of cast iron, particularly in the form of new alloys. The Institute felt, he said, that Mr. Hurst's work in that direction would be of the utmost value to the industry, because it pointed to new opportunities for widening the uses of cast iron, which was, of course, the most valuable of all metals. (Laughter.) People talked of the gold standard, but he wished that we heard less of that and more of the cast-iron standard. Mr. Hurst's researches had shown that in the future the use of cast iron would be immensely greater even than in the past, particularly if the new alloys which were being studied were developed.

The DEPUTY LORD MAYOR, presenting the medal to Mr. Hurst, congratulated him upon his success in this particular branch of metallurgy. Historically, he said, we knew that when the Iron Age had superseded the Bronze Age a tremendous step forward was made in civilisation. Evidently we were not yet near the end of the Iron Age.

The medal was presented amid applause.

Mr. Hurst, responding, said it was difficult to find words adequately to express his appreciation of the honour conferred upon him, but he assured the members that he did appreciate it sincerely and would do all in his power to maintain the honour in the future.

A Vote of Thanks.

The Retiring President proposed a hearty vote of thanks to the Deputy Lord Mayor and Sheriff of Newcastle, and to Sir Arthur Sutherland and Sir William Marris, for having expressed so cordial a welcome to the Institute. The Deputy Lord Mayor represented the chief citizen, and they and their colleagues concerned with local government could do so much to help industry by not allowing rates to become too high. The administration of a city such as Newcastle was a gigantic industry in itself. During his year of office as President he had had the privilege of meeting many Mayors and Lord Mayors throughout the country, and had been impressed in every case by their great devotion to duty, by their attention to the business side of their offices, and by the tremendous burden which these offices imposed upon them. They were doing everything possible to promote the interests of industry, for, after all, they realised that if there were no industries there would be no money with which to pay for local government. The Institute was deeply indebted also to the Sheriff of Newcastle.

Again, the Institute was grateful to Sir Arthur Sutherland, who occupied a very important position in the shipping world, and in many ways was a very valued citizen of the city; and to Sir William Marris, who had had a very distinguished career. The district was to be congratulated upon having the services of a gentleman of his educational attainments, and undoubtedly it would benefit industrially from the high standard of education which was given not only at Armstrong College but throughout the University of Durham as a whole.

The vote of thanks was accorded with acclamation.

The Deputy Lord Mayor, responding, commented upon the Retiring President's reference to rating, and pointed out that the rates in Newcastle amounted to only 10s. in the £1, so that the administrative authorities had achieved some measure of success.

ANNUAL GENERAL MEETING.

The business of the Annual General Meeting was then proceeded with.

Greetings.

The Secretary (Mr. T. Makemson) announced that a number of messages of greeting had been received from foundry associations overseas. Mr. D. Avey, of the International Relations Committee of the American Foundrymen's Association, had cabled:—

> "Please accept behalf American Foundrymen's Association cordial greetings and best wishes successful conference. Sincerely hope British foundrymen encounter early return prosperity."

Messages of good wishes were also received from Mr. Ronceray (President, French Foundrymen's Association), Mr. Ramas (Past-President, French Foundrymen's Association), and from Dr. Geilenkirchen, on behalf of the German Foundry Owners' Association.

A letter expressing good wishes was received from Mr. F. W. Finch, who was the Institute's hon. treasurer for many years, and who described himself as the oldest member of the Institute, and other such letters were received from a large number of members of the Institute who were unable to attend the conference.

Minutes.

On the motion of Mr. J. S. G. Primrose, seconded by Mr. Russell, the minutes of the preceding annual general meeting held at Birmingham on June 10, 1931, were taken as read, and were confirmed and signed.

Council's Report.

On the motion of Mr. R. A. Miles, seconded by Mr. F. W. Rowe, the annual report of the General Council for the session 1930-31 was unanimously adopted, without discussion.

ANNUAL REPORT.

In presenting the annual report for the year 1931-32, and the financial statement for the year ended December 31, 1931, the General Council have to record a year of steady progress in the usefulness of the Institute, in the number of members and in its financial position.

Membership Roll.

During the year May 1, 1931, to April 30, 1932, nine subscribing firms, 70 members (including 13 representatives of subscribing firms), 128 Associate members, 10 Associates have been elected, making a total of 217.

At the end of 1931 a drastic revision of the Membership Roll was carried out, and the names of non-paying members erased. The losses due to this revision, and to resignations and deaths amounted to 142; there is therefore a net increase of membership of 75. The Council notes with satisfaction that 19 members have transferred to higher grades.

Honorary Members.

The General Council have elected Mr. F. J. Cook, Past-President, and Mr. John Shaw honorary life members as a recognition of their services to the Institute over a period of many years.

Finance.

The accounts have been duly audited and the balance sheet certified by Messrs. J. & A. W. Sulley & Company, and a statement of accounts and balance sheet are included in this Report. The thanks of the Council are expressed to the Sheffield Branch who voluntarily returned £50 from their accumulated funds to the general funds.

An analysis of the Membership Roll on April 30 last is given in the following table:—

Branch.	Subscribing firms.	Members.	Associate members.	Associates.	Total.
Birmingham ..	1 (2)	101 (95)	124 (115)	19 (19)	245 (231)
East Midlands ..	4 (5)	50 (45)	94 (96)	3 (2)	151 (148)
Lancashire ..	12 (7)	108 (105)	239 (185)	17 (13)	376 (310)
London	5 (5)	152 (158)	88 (85)	10 (12)	255 (260)
Middlesbrough ..	1 (5)	28 (27)	41 (42)	6 (8)	76 (82)
Newcastle ..	9 (8)	41 (46)	44 (50)	66 (69)	160 (173)
Scottish	6 (4)	83 (81)	181 (166)	15 (21)	285 (272)
Sheffield	7 (6)	76 (81)	75 (82)	10 (9)	168 (178)
Wales and Monmouth	1 (1)	27 (28)	32 (36)	— (1)	60 (66)
West Riding of Yorkshire	— —	36 (31)	54 (53)	2 (2)	92 (86)
Unattached ..	1 —	39 (28)	10 (9)	1 (1)	51 (38)
	47 (43)	741 (725)	982 (919)	149 (157)	1,919 (1,844)

The figures in brackets are for the year ending April 30, 1931.

Obituary.

The losses by death during the year number 16, and include several members who have taken an active part in the conduct of the Institute's affairs.

Mr. Oliver Stubbs, who died on January 4, was elected President in the year 1921, and again in the year 1923. During his term of office as President he visited the United States, and it was largely as a result of this visit and subsequent efforts on his part that the present close international relations between the various foundry associations were established. He was President of the National Iron Founding Employers' Federation from its inception until a short time ago, and the Oliver Stubbs Gold Medal which is awarded each year to a member of the Institute was established by the National Iron Founding Employers' Federation to commemorate his Presidency of both bodies. Until he was stricken by a serious illness in 1928 he took a very active interest in all the Institute's activities, and his wide experience and sound judgment were of inestimable value.

Mr. J. E. H. Allbut was Honorary General Secretary from 1907 to 1913, and died on December 24 last. The Institute owes a great deal to the large amount of very devoted work which he carried out in the early years of the British Foundrymen's Association, as it was then called.

Mr. W. G. Hollingworth, who was General Secretary from 1921 until the end of 1926, became seriously ill some time before his retirement from this position and never completely recovered. He passed away in December, 1931.

Mr. H. C. Dews, President of the London Branch, died after a very short illness in January. He was one of the Institute's younger members who had achieved much during his comparatively short career. He was establishing rapidly for himself a position of authority in connection with non-ferrous metallurgy, and at the time of his death was engaged on important

work on the Institute's behalf as convener of the Non-Ferrous Sub-Committee.

Mr. F. Sanderson died in September, 1931. He was for several years the Honorary Secretary of the Newcastle Branch, and in this capacity gave much devoted and painstaking service to his Branch and to the Institute generally, until continued ill-health enforced his retirement from active work a few months before his death.

Mr. J. Oswald, who was President of the London Branch in 1911-12, passed away in March.

Birmingham and Coventry Conference.

The attendance at the 28th annual conference which was held at Birmingham and Coventry from June 9 to 12, was larger than at any of the Institute's Conferences with the exception of the International Conference in 1929.

The proceedings opened with a Reception given by the Lord Mayor and Lady Mayoress of Birmingham. At the Annual General Meeting on June 10, Mr. A. Harley was installed President, and on Thursday, June 11, the whole of the members and ladies journeyed to Coventry, where they were received in the historic St. Mary's Hall by the Mayor of that city.

The Conference demonstrated again the indebtedness which the Institute owes to the firms who permitted visits to their works, and to the authors of the Papers which were presented.

The Council wish to thank the Lord Mayor of Birmingham, the Mayor of Coventry, the authors of Papers, firms who permitted visits to their works, and all who subscribed to the Conference funds or assisted in any way in connection with its organisation. They especially wish to record their thanks to Mr. F. K. Neath and Mr. F. H. Hurren, the Honorary Conference Secretaries.

Examinations in Foundry Practice.

The scheme of examinations in Foundry Practice and Patternmaking undertaken in conjunc-

tion with the City and Guilds of London Institute, and described in the last Annual Report, was completed in the summer of last year, and immediate steps were taken to bring the syllabuses and the examinations to the notice of foundry proprietors, technical colleges and prospective students.

At the beginning of the Winter Session in October, twenty-nine colleges were operating classes leading up to these examinations. As was to be expected, a few of these classes were withdrawn owing to shortage of students, but twenty-three of them continued their work throughout the session.

The syllabus implies a course of three years, so that it will be at least two years before many of the new students are able to present themselves for the examination. The first series of the examinations, however, were held in April, 1932, and a number of students who had received preliminary instruction prior to the inauguration of the scheme presented themselves for this examination; additionally, thirty-five candidates who had not attended scheduled classes presented themselves for the examination as external students. Successful candidates will receive certificates which will be endorsed by the President of the Institute of British Foundrymen. Additionally, several classes are being held in preparation for the certificates issued by the Union of Lancashire and Cheshire Institutes. The third-year certificates in Foundry Practice of this body will also be endorsed by the President of this Institute.

In the course of their work the Advisory Committee realised that the principal obstacle to the success of this scheme would be the apathy of the persons for whom it was intended, namely, the foundry apprentices. but they feel that the results of the first year have been unexpectedly encouraging and have more than justified the establishment of the scheme.

The proportion of foundry apprentices who attend evening classes has always been exceedingly small, and the preliminary results of this

scheme indicate that as it becomes better known other apprentices will be encouraged to follow the example of those who have gained the certificates, and in the near future it may be confidently expected that a much larger proportion of foundry apprentices will pursue technical studies than has been the case before. Even during its first year, the number of apprentices attending these classes has been probably greater than during any previous session.

The second portion of the Certificates Scheme consists of a modification suited to the requirements of the foundry student of the National Certificate in Mechanical Engineering, issued by the Institution of Mechanical Engineers and the Board of Education, and endorsed by the President of this Institute.

Six technical colleges of high standing have arranged courses for this modified certificate, and already six certificates have been signed by the President of the Institute in respect of National Certificate holders who have also attended the necessary additional courses in foundry work and metallurgy.

The Council appeal to all members of the Institute to interest themselves in these developments in foundry technical training, and bring them to the notice of the students and young men who are associated with them. Several Branches of the Institute have worked actively in conjunction with the employers and the technical colleges in their area with beneficial results, and the Council appeals to the remainder of the Branches to co-operate during the summer in their own areas in the same way.

Technical Committee.

The Technical Committee and its Sub-Committees have held a large number of meetings and have carried out a considerable amount of correspondence.

In view of the large amount of work carried out by the Technical Committee, it is felt desirable that the members should have a complete report of its activities, and this Report is included in this booklet.

Oliver Stubbs Medal.

The tenth award was made in June, 1931, to Mr. John Cameron, J.P., Past-President, "who by his example has done much for the wider dissemination of foundry technique, particularly in the development of new methods dealing with foundry problems, and by his general activities has contributed to the advancement of the technical side of the industry."

Diplomas.

Five diplomas were awarded in June, 1931, for Papers given before the Branches during the previous session, the names of the recipients and the Branches before which the Papers were presented being as follow:—Mr. G. M. Callaghan, Birmingham Branch; Mr. F. Harris, Lancashire Branch (Burnley Section); Mr. J. K. Smithson, Middlesbrough Branch; Mr. R. Liddle, Scottish Branch; and Mr. J. Hird, Wales and Monmouth Branch. The announcement for the award of the diplomas for the session 1931-32 was made at the annual general meeting on June 8.

Buchanan Medals.

The Buchanan Medal is awarded to members of Junior Sections. During the session 1930-31 entries were received from the Lancashire Branch Junior Section only, and the examiners awarded one Buchanan Medal to Mr. Ben Haigh, of the Lancashire Branch Junior Section.

Surtees Memorial Examination.

The Surtees Memorial Fund was instituted by Mr. W. Mayer, Past-President, and the prizes are awarded from a bequest which was left by Mr. Mayer. The examinations are conducted by the Scottish and Newcastle Branches in alternate years. The 1932 examination was held by the Scottish Branch, and the following awards were made:—Senior Grade: Gold medal, Mr. Robert Macnab; second prize, Mr. A. L. Mortimer; and third prize, Mr. David Webster. Junior Grade: Silver medal, Mr. Robert P. Clark. Prizes were awarded to:—Mr. James Liddell, Mr. Walter

McArthur, Mr. David Slater, Mr. Isaac Wilson and Mr. William Cassidy.

John Wilkinson Medal.

The examination for this medal is open to members of the Lancashire Branch Junior Section. The 1931 Medal was awarded to Mr. J. Holmes.

Overseas Foundry Associations.

The outstanding international event during the year was the International Foundry Conference and Exhibition, which were held in Milan. About thirty members of the Institute and ladies attended this Conference, and many of them afterwards joined in an extensive tour of the industrial portion of Northern Italy, and continued to Rome, where the Conference was formally closed by Signor Mussolini.

The Institute has accepted an invitation to participate in the World Foundry Congress and Exhibition to be held in Paris in September, 1932. Particulars of the programme and travel arrangements which are being made will be circulated to members in due course. The Council are particularly pleased to report that the President, Mr. Andrew Harley, has been elected President of the International Committee of Foundry Technical Associations for the year 1932, and will participate in the World Conference in Paris in this capacity.

A meeting of the International Committee of Foundry Technical Associations was held in Milan in September, 1931, and at this meeting the Institute was represented by Mr. John Cameron, Past-President, and by the General Secretary, who is also hon. secretary of this Committee.

Exchange Papers were presented on behalf of the Institute by Mr. V. C. Faulkner at the Convention of the American Foundrymen's Association in 1931, by Mr. J. H. D. Bradshaw at the Conference of the French Foundry Technical Association in 1931, and by Dr. A. L. Norbury at the International Foundry Conference in Milan.

Mr. H. J. Young has prepared the official Exchange Paper for presentation to the Convention of the American Foundrymen's Association to be held in Detroit in May, 1932, and Prof. D. Hanson is preparing the Exchange Paper for the World Foundry Conference to be held in Paris in September.

The Overseas Associations have arranged reciprocal Papers, and at the Conference of the Institute to be held at Newcastle in June, Papers will be presented by Mr. R. F. MacPherran, on behalf of the American Foundrymen's Association, and by Monsieur J. Pillon, on behalf of the French Association.

The Institute continues to co-operate with Overseas Associations directly and through the International Committee on many matters of interest to its members, and on many administrative matters, and it was fully represented at the meeting of the International Cast Iron Testing Committee held in Milan last September.

Kindred Associations.

For many years the Institute has had increasingly close and cordial relations with other technical associations representing different branches of the industry. Several of the branches have held joint meetings with the respective local sections of kindred associations and with local engineering societies. Such cordial relations have proved to be of considerable benefit to the members of the Institute and of other bodies concerned.

British Cast Iron Research Association.

The efforts of the British Cast Iron Research Association to increase its income from the industry to meet the fall in the Government grant while attended with a gratifying measure of success, did not reach the required figure on account of the economic condition of the industry. In these circumstances the Government agreed to fix a maximum grant of £3,000 for the years 1931-32 and 1932-33, subject to the Association raising from the industry the total sum of £6,250 for the first year and £6,500 for the

second year. Subsequently, the Association will be required to raise the original figure of £7,500. It is hoped that the required figure for the current year will be reached, so that the income will balance expenditure, which has been diminished by various economies and staff-salary reductions.

The original programme of investigation undertaken by the Association on the influence of various elements acting jointly in cast iron is approaching completion, and the Research Committee is now planning the programme to be pursued for the next few years. Among the important developments which have taken place are those of some new austenitic cast irons, particularly an iron called Nicrosilal, which is the best cast iron hitherto produced for resistance to heat, and which is a development of Silal, referred to in the last Report.

The balanced blast cupola continues to make remarkable progress and the number of furnaces in operation now approaches a score, on grey and malleable iron. The usual fuel saving is of the order of 25 per cent. to 40 per cent., combined with exceptionally hot metal. Six leading manufacturers have been licensed by the Association to make this cupola. The work on moulding sands has continued, particularly with respect to core sands and refractories. The work done on moulding sands has been strikingly vindicated in a Paper, by Mr. W. Y. Buchanan, to the Scottish Branch of the I.B.F.

Branch Activities.

In response to requests, a Section of the East Midlands Branch was formed at Lincoln during the summer, and has now completed a successful first session's work. In November a Section of the Lancashire Branch was organised at Preston to cater for the large number of founders in Northern Lancashire who wish to meet together regularly to discuss their problems. Nearly eighty members joined the Institute as a result of the formation of this Section.

At the end of November the Scottish Branch held a meeting in Edinburgh, as a result of which arrangements have been made to hold meetings in that city in the interests of present and potential members resident in the district.

The Branches of the Institute have completed successfully a series of lectures, works visits and social functions. In some cases these activities have been carried on in face of considerable difficulties due to the depressed state of trade in certain areas. The President has visited most of the Branches during the past winter and wishes to record his admiration for the devoted work of the Branch officers and Councils.

The number of Papers given before the Branches and Junior Sections was 85, also several informal discussions have been held. These activities are additional to the Papers and visits arranged in connection with the Annual Conference.

By-Laws.

The increasingly wide activities of the Institute and its developments have indicated for some time the necessity of certain alterations in the by-laws. A small committee of the General Council was appointed to prepare a draft revision of the by-laws, and very shortly this committee hopes to present its proposed draft by-laws to the members for their consideration.

General Council.

Four General Council meetings and a large number of committee meetings have been held at Birmingham, Sheffield, London and Blackpool; in addition, the Technical Committee and its sub-committees have held numerous meetings at various centres, and meetings have also been held by the Advisory Committee which works in conjunction with the City and Guilds of London Institute and by its sub-committees.

The average attendance at the General Council meetings was 46. The General Council consists of:—(*a*) Past-Presidents of the Institute, (*b*) members elected by the Branches, (*c*) Branch-Presidents and Secretaries, and (*d*) ten members

elected at the Annual Conference for two years (five are elected each year).

The five members elected in June, 1930, who retire at the annual general meeting on June 8, 1932, are:—Messrs. A. R. Bartlett, A. Campion, F. H. Hurren, J. R. Hyde and W. Jolley. Messrs. Campion and Hyde offer themselves for re-election.

The General Council wish to express their thanks to Mr. W. B. Lake, J.P., for his energetic work as honorary treasurer. The Council also wish to record their thanks to the authors of the many Papers which have been presented; the directorates and staffs of the works which have been visited; to the Branch-Presidents and Secretaries; and to all the members who have contributed to a successful year's working by their active co-operation.

Newcastle Conference.

The twenty-ninth Annual Conference will be held at Newcastle-upon-Tyne from June 7 to 10, when Mr. Victor Stobie, M.I.E.E., President-elect, will be installed President of the Institute.

A. Harley, *President.*
T. Makemson, *General Secretary.*

BALANCE SHEET, DECEMBER 31, 1931.

Liabilities.

	£ s. d.	£ s. d.
Subscriptions paid in advance		165 13 10
Sundry Creditors		421 10 5
The Oliver Stubbs Medal Fund :—		
Balance from last Account	201 11 2	
Interest to date	7 16 9	
	209 7 11	
Less Cost of Medal ..	8 10 0	
		200 17 11
The Buchanan Medal Fund :—		
Balance from last Account	111 7 3	
Interest to date	4 14 9	
		116 2 0

	£ s. d.	£ s. d.
International Conference Fund :—		
Surplus included in General Investments		40 18 11
Accumulated Fund :—		
Balance at December 31, 1930	1,354 1 1	
Add : Excess of Income over Expenditure for the year ended December 31, 1931	74 9 10	
		1,428 10 11
		£2,373 14 0

ASSETS.

Cash in hands of Secretaries :—		
Lancashire	37 18 6	
Birmingham	87 5 7	
Scottish	54 10 8	
Sheffield	33 12 5	
London	80 2 1	
East Midlands	31 5 0	
West Riding of Yorkshire	27 3 3	
Wales and Monmouth	22 5 4	
Middlesbrough	15 10 7	
		389 13 5
Lloyds Bank Ltd.		370 11 7
The Oliver Stubbs Medal Fund :—		
£342 5s. 7d. Local Loan £3 per cent. Stock at cost	200 0 0	
Balance at Lloyds Bank Ltd	0 17 11	
		200 17 11
The Buchanan Medal Fund :—		
£125—£3 10s. Conversion Stock at 78¼	98 6 9	
Balance at Midland Bank Ltd.	17 15 3	
		116 2 0
Investments Account :—		
£450 5 per cent. War Loan at cost	430 9 10	
£300 5 per cent. Conversion Stock 1944-64 at Cost	297 14 11	
£653 19s. Local Loans 3 per cent. Stock at Cost	451 13 8	
		1,179 18 5

	£ s. d.	£ s. d.
Furniture, Fittings and Fixtures :—		
Per last Account ..	77 4 1	
Additions during year	52 5 6	
	129 9 7	
Less : Depreciation 10 per cent. ..	12 18 11	
		116 10 8
		£2,373 14 0

W. B. LAKE, *Hon. Treasurer.*
TOM MAKEMSON, *General Secretary.*

We have prepared and audited the above Balance Sheet with the Books and Vouchers of the Institute, and certify the same to be in accordance therewith.

J. & A. W. SULLY & Co., *Chartered Accountants, Auditors.*

19-21, Queen Victoria Street, London, E.C.4.
April 6, 1932.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1931.

EXPENDITURE.

	£ s. d.	£ s. d.
Postages		119 19 3
Printing and Stationery, including printing of "Proceedings"		664 3 9
Council Finance and Annual Meeting Expenses ..		99 10 2
Medal for Past-President ..		2 5 0
Branch Expenses :—		
Lancashire	120 5 0	
Birmingham	74 18 9	
Scottish	77 0 0	
Sheffield	131 4 6	
London	56 13 8	
East Midlands	48 15 10	
Newcastle	53 19 0	
West Riding of Yorkshire	23 19 7	
Wales and Monmouth	20 7 8	
Middlesbrough	36 4 0	
		643 8 0
Audit Fee and Accountancy Charges ..		12 12 0
Incidental Expenses		69 4 4
Salaries—Secretary and Clerks		641 11 11
Rent and Rates of Office, less Received ..		99 17 6
Income Tax		10 2 6

	£	s.	d.
John Surtees Memorial Examinations :			
Grants to Branches	8	8	1
Subscription International Committee ..	5	0	0
Depreciation of Furniture	12	18	11
	2,389	1	5
Excess Income over Expenditure carried to Balance Sheet	74	9	10
	£2,463	11	3

INCOME.

Subscriptions Received	2,356	9	6
Sale of "Proceedings," etc.	13	10	5
Interest on Investments and Cash on Deposit	51	16	6
John Surtees Medal Fund, Surplus ..	30	18	5
Surplus on Sales of Badges..	10	16	5
	£2,463	11	3

Balance Sheet and Accounts.

MR. W. B. LAKE, J.P. (hon. treasurer of the Institute), proposed the adoption of the balance sheet and accounts for the year ended December 31, 1931, which had been examined by the Finance Committee and the General Council and circulated to members with the annual report. The outstanding feature of the accounts, he said, was that the Institute was a little better off at the end of 1931 than at the end of 1930. Whereas the credit balance on the year's working in 1930 was about £4, the balance in 1931 was about £74. Unfortunately, however, the prospects for the current year were not so good, and it would be very necessary for all branches to exercise the greatest economy if the accounts were to square at the end of the year.

One item of good news was that, following a suggestion by Mr. Stobie (President-Elect), the secretary and auditors had been successful in obtaining a decision that the interest on the Institute's investments should be free of income tax. This would result in the repayment of a sum of about £84 and an annual saving of about £20. The thanks of the Institute were due to Mr. Stobie and to the secretary and auditors for their endeavours in this respect.

MR. J. S. G. PRIMROSE, seconding the resolution for the adoption of the Balance Sheet and

Accounts, urged the opinion of the Lancashire Branch that in future the accounts should include details of the subscriptions received by the Branches and not merely the expenses incurred by the Branches. Details of the Branch subscriptions would have shown that the subscriptions from the Lancashire Branch in 1931 amounted to £554, representing 24 per cent. of the total income of the Institute from subscriptions.

The Balance Sheet and Accounts were adopted.

Report of Technical Committee.

Mr. J. W. Gardom (Convener of the Technical Committee), proposing the adoption of the Committee's Report, which was combined with the Council's Annual Report, said it was the Committee's first report. He appreciated that it was not a big report and that it did not cover a lot of ground, but he pointed out that the Committee, like a marathon runner, was not starting with a sprint, but was making steady progress. The report should be considered as embodying the nuclei from which the future work of the Technical Committee could expand to something really good and worthy of the Institute.

Mr. Gardom took the opportunity to express thanks to Mr. Wm. Jolley, the former Convener, for the work he had done on the Committee.

Mr. F. J. Cook (Past-President), seconding the motion for the adoption of the report, congratulated the Committee upon the great strides it had made in the short time which had elapsed since its inception. The Convener of the Committee had referred to the work in a very modest manner, but, nevertheless, it would redound to the credit of the Institute and to the members of the Committee.

The Retiring President voiced the Institute's regret that Mr. Jolley had resigned the office of Convener of the Technical Committee for reasons of ill-health, and expressed the sincere hope that his health would soon be fully restored and that at some future date the Institute would again have the advantage of

his services in an active capacity. The report contained a summary of the Committee's activities, and among the Papers to be presented to the conference was one giving an account in more detail of the work of the Malleable Iron Sub-Committee. The Technical Committee represented a department of the Institute's activities that was demanding more and more attention, not only with regard to its scope but also its organisation, and he felt sure that under Mr. Gardom's chairmanship the work would be among the most notable ever initiated by the Institute.

The report was unanimously adopted.

FIRST REPORT OF THE TECHNICAL COMMITTEE.

During the year 1930 the General Council considered it advisable that the Institute should have a Committee which would be the medium for dealing with various questions of a technical character which were submitted to the Institute. This Committee would also be a connecting link between the Institute of British Foundrymen and other technical bodies with whom the Institute co-operates on a technical basis. In October, 1930, the Technical Committee was formed for this work. It is constituted of two members of each Branch, these members being elected at the annual meeting of the Branch. From this Committee the following five Sub-Committees were formed:—

Cast Iron. Non-ferrous. Steel.
Malleable Iron. Sands and Refractories,

and each Sub-Committee co-opted other members who were experts on the different subjects.

As these Committees have now had over twelve months' activity, during which eight meetings and numerous Sub-Committee meetings have been held, it is felt desirable that a report should be presented to the members of the Institute indicating the work which has been done up to date.

For the first part of its work the Committee decided to confine itself mainly to exploratory work, with the object of examining, analysing, tabulating by special card system, and correlating knowledge which was already in existence, and to point out the directions in which further information could be usefully sought by way of research or otherwise. If the General Council considered the research work reported upon was to the advantage of the industry, it could then be handed over to the British Cast Iron Research Association to enable them to proceed with further researches if they so desired.

To further co-operate between the Institute's Technical Committee and the British Cast Iron Research Association, a Liaison Committee has been formed consisting of two members of the Technical Committee and two members of the B.C.I.R.A., and the following scheme is the scope of the Institute's Technical Committee's activities and of its co-operation with the B.C.I.R.A.:—

(1) To act on behalf of the Institute and to make recommendations in respect of any technical matter which may be submitted to the Institute by outside bodies and by the British Cast Iron Research Association.

(2) To keep in touch with representatives of the Institute on outside technical bodies, such as the British Standards Institute, and offer guidance on such technical matters as may be required from time to time; to ascertain, where desirable, the opinions of Institute members affecting the industry, which might be useful in framing recommendations to such representatives.

(3) To ascertain the views of the Institute members on current practice and difficulties in the industry with a view to finding what matters most urgently require investigation.

(4) To furnish the Research Association with material that may be required in connection with any investigation undertaken at the suggestion of the Institute, and as far as possible

to furnish samples which would assist the Association in its general investigations, the results of these investigations to be available to the Institute Technical Committee.

(5) To collect and disseminate technical and scientific information of interest to the industry and to assist generally in the education of the industry.

(6) To furnish suggestions to the Association which might be of assistance in carrying out the latter's research programme. Copies of the Association programmes, when issued, are to be forwarded to the Technical Committee for their guidance.

At an early stage of the Technical Committee's work it was considered advisable to tabulate all references in the technical Press dealing directly or indirectly with foundry work. The Committee have done this, and also made such references available to all members of the Institute in the form of a periodical Bulletin which is circulated monthly by each Branch-Secretary. The Committee is indebted to Mr. V. C. Faulkner, Past-President, who compiles this Bulletin each month.

Each Sub-Committee has collected and tabulated specifications dealing with its own subjects, with a view to simplifying and standardising such specifications. They have also answered official queries addressed to the Technical Committee by Subscribing Firm Members of the Institute and other members relating to technical and practical problems of the foundry industry.

The Sub-Committees are so constituted that the arrangement of meetings is extremely difficult, the members of some Sub-Committees residing over 300 miles apart. Much of the business has of necessity been carried out by correspondence, which is rather slow, but the following brief reports of the various Sub-Committees show that a considerable amount of valuable work has been accomplished.

WM. JOLLEY, *Convener,*
Technical Committee.

Sub-Committee on Cast Iron.

Convener: Mr. P. A. Russell, B.Sc.

This Sub-Committee has examined specifications for iron castings from 21 authorities, and has classified them on a standard card-recording system so that the information they contain is readily available for members of the Institute.

Each specification has been examined individually by all members of the Sub-Committee, and where they considered it advisable they have recommended that the firms are approached with a view to changing over to the recognised standard specification. The work connected with specifications is not yet completed.

The Sub-Committee have now assembled available published physical data on cast iron for: Specific gravity, specific heat, latent heat of fusion, thermal conductivity, thermal expansion and electrical conductivity. These figures are available to all members of the Institute on application.

At the present moment the Sub-Committee have under discussion questions relating to wear tests, contraction allowances, and high-test cast iron. They have drawn up a report on cast-iron testing for presentation to the International Committee on Testing Cast Iron summarising the work done by the Test Bar Committee of the Institute.

Sub-Committee on Non-Ferrous Metals.

Convener: Mr. J. S. G. Primrose, A.R.T.C., M.I.M.M.

This Sub-Committee has held several meetings under two sub-conveners, and in addition has done most of its work by means of correspondence, due to the wide geographical distribution of its members and co-opted helpers. With the object of standardising specifications governing the production of alloys, the Sub-Committee members have considered in detail the requirements issued by twelve firms and authorities, covering 67 alloys in 48 specifications, and further collections are solicited from interested

bodies. Most of the specifications call for no comment; a few appear to be incomplete, and several are deemed capable of improvement on the lines of suggestions to be communicated to the firms concerned. One particular specification has called forth such divergent comments that it is clear that the diversity of uses may sometimes militate against the adoption of general specifications. A collection is being compiled in regard to the nomenclature and composition of proprietary alloys, and also standard data covering the important physical properties of non-ferrous metals and alloys, and this work is intended to be of use to the foundry worker. The first part of the data, dealing with the constants for thermal conductivity, electrical conductivity and specific heat has now been compiled, and is available to members upon application.

The chief work so far undertaken has been to collect and record experience as to the best method of casting separate test-bars of gun-metal, so as to obtain agreement as to the pattern and method of running, which will show the best properties of the alloy itself. Four types of test-bars have been selected, and when a sufficient number of results are forthcoming a report on the sub-committee's finding will be published.

Sub-Committee on Steel Castings.

Convener: Mr. R. J. Hyde, A.M.I.Mech.E.

Acting upon the original instruction, the Sub-Committee on Steel Castings have classified the existing steel casting specifications, and have approached various authorities, chiefly through the general secretary of the Institute, and asked them to be good enough to forward copies of their steel castings specifications. Thirty-five replies have been received, accompanied in most cases by a definite specification. The Sub-Committee have noticed that in very few cases a comprehensive specification is used. The majority use British Standard Specifications, and some have recently put this in as an alternative to their older specifications, and it is necessary for the contractor, when commencing

his work, definitely to agree with the engineers as to which specification he is to work. Other specifications appear to be extracts from the British Standard Specification issued by the engineers under a distinctive number or reference letter.

The Sub-Committee have therefore prepared a report showing 16 detailed clauses which are given in the most complete specifications, and have entered opposite each of these clauses the demands of each separate specification. The test almost universally specified is the tensile test in its simplest form, namely, maximum stress and elongation. The cold-bend test is the next in order of general use, coupled with a drop test or destruction test. Very few specifications require the yield point or the reduction of area, and still fewer call for a Brinall test. Many of the other points refer to general instructions to the Inspector, so that, on the whole, reasonably uniform conditions are provided for.

We have presented our report with the 16 detailed clauses clearly shown, and it is therefore easy to compare all the tensile tests or all the Brinell tests, and one can readily judge whether any specification is reasonable when compared with the others.

The question of approaching an engineer and requesting him to modify his tests was fully discussed at two committee meetings, and it was decided that, for the time being, the particular test complained of must be regarded as a modified form of British Standard Specification, Class "C," and, therefore, we did not request the general secretary to take any further action.

A number of specifications for alloy steel castings were received, but as alloy steel castings are not within the scope of this Sub-Committee's instructions, we have done nothing with them.

On the whole, the Sub-Committee is satisfied that steel castings specifications appear reasonable and free from anomaly. Whether the very high quality called for could be reduced somewhat in order to meet foreign competition

abroad, is a matter which should be carefully considered, and we believe the matter is being raised in competent quarters. The chief point of the proposition is that, if Continental and American steels can be supplied to lower specifications, it is unfair to handicap the British manufacturer by making him work to a standard specification which entails more expensive material.

Sub-Committee on Sands and Refractories.

Convener: Mr. N. D. Ridsdale.

Since the testing of foundry sands is only beginning to be appreciated and practised on a relatively small scale in this country, it will be realised that there are no specifications available which are worth mentioning, and this Sub-Committee felt that its first duty was to agree upon the methods of testing foundry sands.

The following decisions have been unanimously agreed upon:—

(1) That for the time being the consideration of the methods of sand testing should be confined primarily to green sands.

(2) That the consideration of methods of sand testing should be given in the first place to tests for foundry control rather than for research work.

Overhang Test.—It was decided to omit this test at present owing to its unsatisfactory nature.

Compression Test.—This test should replace the overhang test and should be undertaken with the size of test-piece recommended by the British Cast Iron Research Association, viz., a cylinder 1.128 in. dia. and $2\frac{1}{4}$ in. long. This shape is more satisfactory than the American Foundrymen's Association test-piece 2 in. dia. 2 in. long.

Constant Ramming.—This could be done by the method adopted by Mr. W. T. Buchanan, mentioned in Dr. Skerl's Paper on "Sand and Sand Testing," given to the Institute at the Birmingham Convention, 1931,* whilst variable ramming

* Proceedings, "Institute of British Foundrymen," Volume XXIV, page 151.

could be performed by the method recommended by the Research Association in its Research Report on Sand Testing.

Permeability Test.—This test could be made on the Research Association permeability test-piece, and the permeability could be measured either by passing coal gas through it, according to the recommendation of the Research Association, or by passing a known volume of air through it at a given pressure and noting the time taken. Results by the two methods of measurement would then, no doubt, be comparable.

Moisture Test.—Experiments are being carried out on a member's suggestion for measuring the moisture content of sand by the difference in the electrical resistance of different sands.

A number of experiments were made by one member of the Sub-Committee to compare the two methods of measuring permeability in green sands. The results were very encouraging, and it was felt that the work should be followed up by further experiments, mainly on iron-moulding sands, in order to arrive at definite conclusions.

This Sub-Committee hopes that in a few months' time it will be possible to recommend to the Technical Committee certain definite conclusions as to the best methods of making simple foundry control tests on green sands, embodying the combined advantages of the several different types of test that are obtainable at present.

Sub-Committee on Malleable Cast Iron.

Convener: Mr. J. W. Gardom.

As requested by the Technical Committee, this Sub-Committee has collected as many as possible of the available specifications controlling the manufacture and inspection of malleable cast iron. The examination of these specifications showed that, generally, the foundation was governed by the British Standards Specifications (B.S.I.), Nos. 309 and 310, and it was considered advisable to press for the universal adoption of these specifications.

The possible improvement by the addition of clauses to make the specifications suitable for all requirements, was the work undertaken by the Sub-Committee. The experiments and discussions are fully reported in the *résumé* of work to be presented as a Paper by the Malleable Iron Sub-Committee of the Institute's Technical Committee at the Annual Conference of the Institute to be held in Newcastle in June, 1932.

Awards of Diplomas and Buchanan Medal.

The SECRETARY announced that Diplomas had been awarded to the following in respect of the past year as follow:—

MR. T. R. TWIGGER, for a Paper read before the Birmingham Branch on "Some Recent Developments in Automobile Cast Irons"; MR. W. WEST, for a Paper before the Lancashire Branch on "Low Total-Carbon Cast Irons and their Service to the Foundry Industry"; DR. GUIDO VANZETTI (of Milan), for a Paper read before the London and Lancashire Branches on "The Italian Steel Foundry Industry"; MR. W. Y. BUCHANAN, for a Paper before the Scottish Branch, on "Sand Testing in the Foundry"; and DR. H. W. SWIFT, for a Paper to the West Riding of Yorkshire Branch on "Modern Practice in Cast-Iron Testing."

Entries for the award of the Buchanan Medal had been received only from the Lancashire Branch. The medal was awarded only to members of the Junior Sections, and the examiners had awarded a Buchanan Silver Medal to Mr. Jack Holmes, of the Lancashire Branch Junior Section. (Mr. Holmes was the recipient, for the last two consecutive years, of the John Wilkinson Memorial Medal of the Lancashire Branch.)

ELECTION OF OFFICERS.

President.

The RETIRING PRESIDENT, proposing the election of Mr. Victor Stobie, of Newcastle, as President for the ensuing year, emphasised that he possessed every qualification for this important office, and would carry out the duties in a very

efficient and dignified manner. Mr. Stobie was well known throughout the industry, in the development of which he had played a very distinguished part, and as the result of reaping some of the fruits of his efforts he had plenty of leisure in which he would be able to attend to the affairs of the Institute. The members could feel assured that under his guidance the Institute would go on to greater prosperity during his year of office. One could not say all that one felt on occasions such as this, said Mr. Harley, but he personally was proud that Mr. Stobie was to succeed him, and the Institute had every confidence in him as its President.

Mr. V. C. Faulkner (Past-President), seconding, said it was peculiarly fitting that he should have the opportunity of doing so, because he had had contact with Mr. Stobie from three angles. For five strenuous years he had been Mr. Stobie's assistant, and had found him to be a brilliant metallurgist and electrical engineer, a very fine linguist, an inventor and a just and enthusiastic employer. Secondly, both prior to that period and ever since, Mr. Stobie had been his friend, staunch and loyal. Thirdly, he had had contact with Mr. Stobie as a colleague in the Institute, and had found him both enterprising and enthusiastic. His well-known enthusiasm and enterprise for anything which he took in hand would make for the still greater success of this already successful Institute.

The resolution was carried unanimously, and Mr. Stobie was invested with the Presidential Chain and Badge of Office, amid prolonged applause.

Addressing the meeting, he said he felt very deeply the great honour that had been conferred upon him. He appreciated that brilliant examples had been set by his predecessors, men whose enthusiasm for their work had brought the Institute to the position it had attained; he would do his best to consolidate the position, and hoped that when he handed on the office to his successor the wheels would still be running as quickly and as sweetly as at present.

A Vote of Thanks to Mr. Harley.

The PRESIDENT said his first duty was most pleasurable and gratifying; it was to propose that the thanks of the Institute be accorded Mr. Harley for the wonderful things he had done for it during the past year. Mr. Harley had set a brilliant example, and one which would give his successors much to think about. His command of the Council—a rather necessary quality at times—(laughter)—and his success in other directions showed what a man of such great tenacity of purpose could do and how easily he could deal with situations which others might find very difficult. He had shown also that he had a wonderful bent for work. Presumably that was a legacy of the land from which he came, and from which no Englishman ever returned without being wiser, and lighter. (Laughter.) Mr. Harley had been so impressed by the amount of money that the Scots could obtain from the Englishmen who visited Scotland that he had decided to come right amongst them. In addition to his business capacity, he had few equals on the social side, and he had gone his rounds assiduously. The President added thanks to Mrs. Harley for the very gracious and self-sacrificing way in which she had allowed him to carry on the work of the Institute—(hear, hear)—which owed to them both a debt of sincere gratitude.

MR. F. P. WILSON, J.P. (Past-President), seconding, recalled that Mr. Harley had succeeded him, and added that he had learned of a great many of his own defects and failures by watching Mr. Harley's successes. All members of the Institute realised the great debt they owed to Mr. Harley for his excellent conduct in the chair of the Institute.

The vote of thanks was carried with acclamation, and the Past-President's Medal was presented to Mr. Harley by the President, who expressed the hope that Mr. Harley would live long to enjoy the sentiment it represented.

MR. HARLEY, responding, said he felt that what he had been able to do was very little as

compared with what he had intended to do; nevertheless, he hoped his efforts had benefited the industry. He had found the work worth while, because, quite apart from the scientific and technical side of the Institute's activities, he had made many valuable friendships, and that was a source of gratification to him on relinquishing office. He remembered with gratitude how splendidly he had been supported and how friendly and genial everyone had been, not only at Council meetings but also during his visits to the Branches. He thanked the Branches for their kindness not only to himself but also to Mrs. Harley, who had thoroughly enjoyed those visits. After all, friendship was the most valuable thing in the world, and if he could retain the friendships he had formed within the Institute of British Foundrymen he would always feel that his association with it had been one of the most precious activities of his life.

Senior Vice-President.

The PRESIDENT proposed the election of Mr. C. E. Williams, of Cardiff, who had served as Junior Vice-President during the past year, to the office of Senior Vice-President. Mr. Williams, he said, had considerable interest in everything the Institute did, and had been connected with the Institute since 1906, both indirectly and directly.

MR. HARLEY (Past-President), seconding, said he had a great regard for Mr. Williams. When he had had the pleasure of visiting the South Wales Branch at Cardiff, he had found that Mr. Williams' family were held in the highest honour and esteem in the district, and in him the Institute would have a Senior Vice-President who would do it honour.

The resolution was carried unanimously.

MR. WILLIAMS expressed his thanks for the honour conferred upon him. He felt that it would be difficult for him, in due course, to follow the example which he felt sure Mr. Stobie would set as President, but he looked forward

to the pleasure of inviting the Institution to visit Cardiff. The members could not have had a better reception than had been accorded them in Newcastle, but he assured them that when they visited Cardiff they would have a very happy time.

Junior Vice-President.

Mr. R. A. Mills proposed the election of Mr. Roy W. Stubbs as Junior Vice-President. He recalled that Mr. Stubbs had served the Lancashire Branch for two years as President, and during that period the membership of the Branch had increased very considerably. The Branch was still the largest in the Institute, and that was due to a great extent to the activities of Mr. Stubbs. He bore a very honoured name, and no doubt he would render to the Institute services which would add lustre to that name.

Mr. Wesley Lambert, C.B.E. (Past-President), seconding, said he had watched the activities of Mr. Roy Stubbs for some years, and felt confident that the Institute would do the right thing if it elected him Junior Vice-President. He was a young man, very genial, with a very happy way of expressing himself, and he had great enthusiasm for the welfare of the Institute. There was another reason why Mr. Lambert was glad to be able to second this proposal. It was due to Mr. Stubbs' late uncle, Mr. Oliver Stubbs, that he personally had served as President of the Institute. There was a time when he had thought he would not be able to accept that high office, but Mr. Oliver Stubbs had told him that he had got to do it, and had assured him of his support. Again, he had the honour of holding the Oliver Stubbs Gold Medal. In Mr. Roy Stubbs the Institute would have a very energetic Vice-President, and one who would do honour to the Institute.

The resolution was carried unanimously.

Mr. Stubbs, after expressing his cordial thanks for the honour, said he regarded it as an honour

not so much to him personally as to the Lancashire Branch. The members of that Branch were very grateful, through him.

Auditors.

On the motion of Mr. A. Campion, seconded by Mr. V. C. Faulkner (Past-President), Messrs. J. & A. W. Sully & Company (Chartered Accountants) were re-elected auditors.

Appointment of Trustee.

On the motion of the President, seconded by Mr. F. P. Wilson, J.P. (Past-President), Mr. A. Harley was unanimously elected a Trustee, on the Council's nomination, to fill the vacancy created by the death of Mr. Oliver Stubbs.

Members of Council.

The ballot for the election of five members to fill vacancies on the General Council resulted in the election of the following: Mr. A. Campion (Glasgow), Mr. F. J. Hemming (Walsall), Mr. B. Hird (Newport, Mon), Mr. J. R. Hyde (Newcastle, Staffs) and Mr. J. M. Primrose (Falkirk).

PRESIDENTIAL ADDRESS.

The President then delivered his Presidential Address, as follows:—

The field of thought and of operation of our Institute is a branch of metallurgy practised in a remarkably large variety of industries. The metals used in these different industries vary in character to such extent that what one man must do with his material to increase a certain quality is oft-times the reverse of what the next man should do with his different metal for similar direction of result.

To such an Institute as ours, an ideal Presidential Address should, therefore, be a talk to the sculptor in bronze as well as to the maker of locomotives; to the die-caster as well as to the

bell founder; to foundrymen in a hundred different industries, who may be said to cast their daily bread in moulds.

There has been a certain difficulty in finding a topic, common to all these branches of our work, which was suitable for the theme of the present address. I did not wish to survey the year's progress in foundrywork, nor to present a portfolio of statistics, so I have chosen to speak in a style impossible on other occasions. I propose to talk more especially to one section of founding which, in my humble opinion, has a wide-open field in front of it, notwithstanding its past accomplishments. That section is the largest one: it is that of ironfounding. Some remarks will have, nevertheless, more general application.

The wide-open field which I suggest ironfounding has in front of it is the adoption by that industry, as a whole, of a more exhaustive scientific investigation of their metal. At present, what investigation work is being done is left to the few.

A common thought leads one sometimes to imagine—vainly, it is true—that one's own occupation in life calls for more care than those of others. Thus I allow myself, for the purpose of this talk, to tell the ironfounder what a steelman, who has had a bird's-eye view of some ironfoundries, thinks he would do in their circumstances! To avoid putting my foot in a hornets' nest, I take refuge behind a further suggestion: this talk is to those who agree with me!

Cast iron is different from most other metals in that it can only be used in the form of a casting, for which obvious reason the ironfounder does not have to compete, as do the brassfounder and the steelfounder, with a competitor producing a more or less similar material in the wrought form. This lack of a competitor has not helped the ironfounder to put forward his greatest efforts. I want to suggest to the ironfounding industry a mental picture of such a competitor, and to ask it to act as it would have to do were such an ogre trying to steal away its order-book.

A New Industry?

If this conjectural wrought-cast-iron industry existed, its practitioners would have had to ascertain—if other wrought-metal industries are a guide—the infinity of variations of which its metal was capable. It would have found which composition gave the best resistance to rupture by tension and shock; which the greatest elasticity; the highest resilience; the least permanent deformation by heat or other stress; the variations of characteristics by heat-treatment; the greatest toughness for a given machinability. These and other essential inquiries would have had to be made by our hypothetic wrought-cast-iron practitioner, and he would have become a redoubtable competitor to the ironfounder who had not equally equipped himself with all such fundamental knowledge of his metal.

There are still ironfounders—shall I say: outside this Institute?—who are prone to regard their castings as the result of So-and-so's pig-iron and such-and-such scrap, plus a black-sand mould. If a casting does not turn out satisfactorily, So-and-so's pig-iron is suspected of having "gone to the dogs," or such-and-such scrap is "not what it used to be." It is necessary, to-day, that the ironfounder should know that his metal is no longer a mystery. This does not imply that all, or anywhere near all, is known about it; but sufficient can be ascertained to explain the vast majority of happenings, good and bad, in a foundry. It is within the reach of all ironfoundrymen to have a fair understanding of the basic principles of the metallurgy of cast iron by an extent of study well in proportion with the resulting advantages.

A Chemist not Necessarily a Metallurgist.

To a foundryman who desires to acquire as quickly as possible a working understanding of ferrous metals, I would recommend the study of physics even more than chemistry, for the principles governing successful metal-production and founding involve more varying physics than varying chemistry. A chemist is not necessarily

a metallurgist, even though he may have spent a long time in a metallurgical laboratory and be highly skilled in the analysing of metals. Such skill is of little help in solving the major problems which occur in the foundry.

The metallurgist's principal section of chemistry is what, for the sake of distinction, I will call "thermal chemistry." The chemistry of the laboratory is "cold chemistry." Thermal chemistry may be studied by, first, acquiring a knowledge of the technics of combustion. If the student has only time to devote himself to a single study—though I cannot possibly commend such limitation—the acquiring of a thorough knowledge of the physics and chemistry of combustion will be the most remunerative study he can make. With such knowledge in hand he will appreciate, more than he might have thought possible, a considerable number of happenings in the day's work.

Pioneer Work.

The way to a systematised study of cast iron was shown, as far back as 1885, by Emeritus Prof. T. Turner, of Birmingham University, an esteemed Oliver Stubbs Medallist of our Institute. He made a comprehensive series of pure cast irons to which he added increasing percentages of silicon. His researches, showed, for the first time, the effects of varying that most important element. One could have hoped that such a fruitful investigation would have encouraged ironfounders to further the quest for all similar basic information. We know that private interests have pursued certain directions of work; in some cases with great recompense to themselves. We do know also—and this is the pith of my message to the ironfounding industry—that thorough research has been done in all the usual elements in the case of all other industrial metals.

If the grey-iron foundry industry possessed reasonably tabulated figures showing, for iron made under given conditions, the effect of a variation in the percentage of each of its normal

constituents and, additionally, on the lines so excellently started by our esteemed member, Mr. J. E. Hurst, the effect of varying heat-treatments on those irons, we could picture an industry still more potent to help the engineer and, through him, the world.

Fields for Research.

Considerable essential investigation has yet to be done on the influence of blast-furnace and cupola operation on the ultimate quality of cast iron of given composition. One may have used at different times, as raw material for castings, pig-iron of approximately similar composition procured from two sources at a distance apart, or one may have used similar composition iron made at two different periods in the same blast furnace. Why can the resulting castings from each lot of pig-iron have different properties when the composition is similar? I am assuming moulding conditions to be constant. Are such occurrences imaginary? If not, do they result from differences in the raw materials of the blast furnaces; in the operation of those furnaces; or in the cupola practice? And can a uniform product be ensured at all times by skilful foundry control notwithstanding any previous history of the iron, so long as its composition is correct?

If I dared to answer my own questions, I should probably be found answering the last one in the affirmative. As I have the advantage of your not discussing this address, I will not pursue this arguable view at greater length than to ask you to picture what it really portends if a skilful metallurgist has, with to-day's knowledge and facilities and with technical dicipline in the foundry, the wherewithall invariably, or almost invariably, to produce good-casting metal notwithstanding inconsistency of quality in his raw material.

Text-Book Fallacies.

As my efforts in this talk are centred on encouraging the everyday ironfounder to take a greater scientific interest in his wonderfully

versatile metal, I feel I ought to give, at the same time, a very unusual type of warning. Whilst the ironfounder is pursuing his technical studies, it is advisable for him, when experimenting in new directions, not to be unduly controlled by supposed axioms from text-books on metallurgy if they do not coincide with the results of well-conducted experiments he has made. It happens, not alone in isolated cases, that statements based on little evidence, or even unsupported expectation, are copied from text-book to text-book until they assume the aspect of accepted facts. A glaring example kept cast-iron metallurgists, until recently, from serious study of the heat-treatment of cast iron. The text-books wrongly said, in perfect unison, that no sufficient advantage resulted. Dr. Percy, in his famous book on metallurgy, said no steel would ever displace iron for the armour of warships! Another example, this time referring to refractories, came to my knowledge some years ago. A well-known Welsh steelworks installed a mixer furnace to hold some 200 tons of molten blast-furnace metal. It was lined with magnesite bricks. The designer of the plant, who had had no previous experience of basic linings, primed himself with all he could gleam about magnesite bricks from the best text-books on refractories. Shortly after the mixer had been put into commission, one of its ends burst open. A seething mass of molten metal poured out into the melting shop. I chanced to meet the designer the day he heard of the disaster. He said nothing about it until after ascertaining my experience as to whether such bricks expanded or not on heating. The reply was, of course, in the affirmative. He then told the story of how he had based himself with confidence on the text-books, all of which said those bricks neither expanded nor contracted on heating. To-day, the text-books still say the same.

Dangers of Exterpolation.

A parting suggestion to the intending investigator is to learn early that a metallurgist should

never attempt mathematical deductions from his discoveries. He must not conclude, for example, that because a 1 per cent. manganese steel is tough and a 15 per cent. one tougher still, a 5 per cent. one will be of intermediate toughness. Nor must he tell himself that because iron is made non-magnetic by an addition of some 30 per cent. of nickel, it follows that greater additions cannot make it again magnetic. He must not deduce that because wrought iron increases in electrical and thermal resistivity as it approaches its melting point, cast iron does the same. Such presumptions would lead his metallurgy to disaster.

I have spread my remarks over a broad series of points in order to express to the ambitious ironfoundryman that it is essential for him, just as for every other metallurgist, to plump for the knowledge which waits on nearly every bit of thoughtful experimental work he is prepared to undertake.

We receive encouragement, from every direction, to free ourselves in metallurgical matters from the rut of unenlightenment, and to strive forward with the adventurous mind of the explorer bent on making useful discoveries in a promising land. If we observe that all-essential practice of keen observation, and arm ourselves with a working knowledge of the sciences, we are almost certain to discover something new and valuable before our labour is ended. It is rare for such a journey to be taken in vain.

Vote of Thanks to the President.

Mr. A. Harley (Immediate Past-President) proposed a hearty vote of thanks to the President, and congratulated him upon the original matter contained in the address; it had been very suggestive, and would be studied carefully by all concerned, for their own benefit. In industry to-day the technical and scientific investigator and the technical man who was responsible for the routine work should be held in much higher regard than they were, and should not be at the mercy of the waves and winds of

industrial ups and downs. How could such work be carried out properly under the conditions existing in so many places to-day? Such work was exceedingly difficult; sometimes those in control of industry did not even understand it, and consequently did not appreciate its true value, except, perhaps, when the results emerged. Industry was being carried on the shoulders of these scientific and technical men, and it was not the financial consideration which kept industry going, although many people considered that it was. Without the scientific and technical men, industry would die. That was why the Institute should always insist upon the high status of the work these individuals were responsible for, and for which the Institute was the bulwark and spokesman. The President's address was admirable.

Mr. J. Smith (President, National Iron Founding Employers' Federation), seconding, said the address was such as he had expected from Mr. Stobie. Whereas the technical side of the industry might be highly appreciated at the present time, perhaps we were a little apt to forget the practical side, and we must never forget that there were moulders as well as metallurgists and chemists. Many years ago, good practical Papers were presented at these conferences, but nowadays the Papers seemed to be scientific from top to bottom. It was of no use making high-class material and putting it into bad moulds. He had enjoyed the Presidential Address thoroughly.

Mr. Harley, submitting the vote of thanks to the meeting, pointed out that he regarded the moulder as a technical man, and he appealed that the imaginary fences between one class of worker and another should be knocked down.

The vote of thanks was carried with acclamation.

The President, commenting on Mr. Harley's remark that scientific and technical men should not be at the mercy of the ups and downs of industry, asked how it was possible to avoid that, because the result of the "downs" was

that certain works closed and the poor metallurgists had to go. As to the line of demarcation suggested by Mr. Smith between different workers, he was glad to hear Mr. Harley point out that they were really more imaginary than real. If the practical moulder did not count himself a technician, then what was a technician? If he were practical he was dealing with the technics.

The following Papers were then presented and discussed: —

"Some Notes on Moulding and Pouring Practice," by J. Pillon.—(Exchange Paper presented on behalf of the Association Technique de Fonderie.)

"Quantity Production of Grey-Iron Castings," by J. O'Sullivan, of Henry Ford & Son, Limited, Cork.

The ladies visited places of interest in Newcastle under the guidance of the Ladies' Committee, and on the adjournment of the Conference at 12.30 members and ladies lunched together at the County Hotel.

During the afternoon parties of members visited the following works: —

The North Eastern Marine Engineering Company, Limited, Wallsend-on-Tyne.

Messrs. A. Reyrolle & Company, Limited, Hebburn-on-Tyne.

Sir W. G. Armstrong, Whitworth & Company (Iron Founders), Limited, Gateshead-on-Tyne.

The Norwood Coke Ovens of the Priestman Collieries, Limited.

The ladies inspected the Cremona Toffee Works of A. S. Wilkins, Limited.

ANNUAL BANQUET

On Wednesday evening, June 8, the annual banquet of the Institute was held at the Grand Assembly Rooms, Barras Bridge, Newcastle-upon-Tyne. There was a distinguished gathering of members and guests, accompanied by their

ladies, and after dinner they enjoyed dancing until a late hour.

The President was in the chair, and was accompanied by Mrs. Stobie. The company also included the Deputy Lord Mayor and Deputy Lady Mayoress of Newcastle (Councillor and Mrs. J. Crosby), the Sheriff of Newcastle (Councillor J. Leadbitter), Prof. Henry Louis, M.A., D.Sc., A.R.S.M. (Bessemer Medallist, and a Past-President of the Iron and Steel Institute and the Institution of Mining Engineers), Lieut.-Col. P. H. Ionides, D.S.O. (Vice-Chairman of the Armstrong Whitworth Group), Mr. E. J. George (managing director, Consett Iron Company, Limited), Mr. W. Scott (Senior Vice-President, Newcastle and District Branch of the Institute) and Mrs. Scott, and many Past-Presidents of the Institute.

The Toasts.

The loyal toast having been honoured,

Lieut.-Col. P. H. Ionides, D.S.O., proposed "The City and Commerce of Newcastle-upon-Tyne" in a speech which was both witty and serious. In the course of it he said that Newcastle was a city of extraordinary historical interest. The records extended back to the time of Hadrian, the first Roman Governor of this district, most of whose time seemed to have been spent in keeping the unruly Scots on the proper side of Hadrian's Wall. There was a perpetual state of agitation, and Col. Ionides suggested that the original Roman training and, after the departure of the Romans, the continual raids of the Scots, had developed a hardiness, a physique and character in the Northumbrians which had been largely responsible for the success of the industries of Newcastle in later years.

He referred to the high-level bridge over the Tyne at Newcastle as a feature of peculiar interest to foundrymen. It was designed and built by Robert Stephenson, who was the son of the Robert Stephenson who had become so famous in connection with railway development. The bridge consisted of six spans, each of

125 ft.; in each span there were four arches, and in each arch there were four segments, and they were all made of cast iron. The bridge was built in 1849, and, with very slight additions in the form of steel ties, it had stood to this day. It carried a main-line railway, a main road and two lines of tramways, and the fact that it was carrying modern traffic was an extraordinary tribute to the builder.

Discussing Newcastle's coal interests, he said that normally Newcastle exported about 18,000,000 tons of coal per annum. Alongside the coal industry there was the shipbuilding industry. To Newcastle belonged the credit of having built the first turbine-driven vessel, the "Turbinia," with which Sir Charles Parson's name was so closely connected. This vessel was the pioneer which had led ultimately to the building, on the Tyne, of such ships as the "Mauretania," which had held the speed record for the Atlantic crossing until beaten by the "Bremen" and the "Europa," which were 20 years younger. The normal output of shipbuilding in Newcastle was 350,000 tons a year, and the normal output of marine engines was approximately 375,000 indicated horse-power, or thereabouts. It was extraordinarily tragic to note the idleness in the shipyards and the marine-engine shops under the prevailing conditions of depression. We were suffering—and the Tyneside suffered almost more than any other part of the country—from the complete collapse of international trade. The first sufferer from such a collapse was the shipbuilding industry, because there was no demand for ships to carry goods from one country to another. That was the reason why, on the Tyne, there were dozens of berths empty.

New Tyneside Industries.

All of us would turn our eyes to Lausanne, to the Ottawa Conference, and to the later conference which it was expected would be held in London, on international trade. He, personally,

believed that the key to the situation lay in the United States of America. Ever since the war the United States had been exacting tribute from an impoverished Europe, and, by reason of the high tariffs operating in America, that tribute could be paid only in gold. The result was that America had accumulated most of the gold in the world, so that other countries could not trade with the United States or with each other. Thus we had the picture of the United States almost choked with gold, and some of its people almost starving. The condition of affairs there was really lamentable, and those who had not friends living there had no conception of the conditions. His belief was that the recovery of the world would come with the recognition in that great country of the injustice of insisting upon the payment of reparations and war debts under existing circumstances.

In view of the prevailing depression, Newcastle had had to turn its attention to industries which were entirely new to it, and he could not find words with which to pay an adequate tribute to the amazing fertility and adaptability of the Newcastle engineer and foundryman. Marine engineering was dead, and steam locomotives were not being ordered, and the Armstrong works had had to turn attention to commercial vehicles and other products which were not made in Newcastle hitherto. The manner in which not only the staff but also the workmen had tackled the new problems spoke volumes for their ability and engineering genius. They had been able to produce the most difficult types of castings after comparatively few weeks' experience, whereas most people required years of experience. Lighter industries also were growing up in the city, and they would help during the difficult times until shipbuilding and coal mining, upon which Newcastle had depended so much, recovered.

Three Notable Anniversaries.

The Deputy Lord Mayor of Newcastle said he was in some difficulty in responding to the

toast, because on occasions such as this he was sometimes called upon to listen to attacks upon the administration of the city, and declarations that the rates were far too high and that the money collected was badly spent. On this occasion, however, there was nothing of that kind to reply to, so that he did not know what to say. (Laughter.) However, he must assume that Colonel Ionides and the great undertaking which he represented were entirely satisfied with the administration of the city, with the manner in which the money was spent and with the assessments made upon them for local rates.

During the week of the conference, there were being celebrated in Newcastle the anniversaries of some rather important events in local and national history. Gas lighting was first introduced into Newcastle on June 6, 1807. He believed that gas was an important factor in some classes of foundry work, so that it was perhaps appropriate that gas should be referred to on this occasion. June 7 was the anniversary, and the centenary, of the passing of the great Reform Bill of 1832, for which the Grey family, who were so closely concerned with Newcastle, had been principally responsible. Charles, Earl Grey—a monument to whom was erected in the centre of Newcastle—was Prime Minister at the time of the passing of the Reform Act. Again, June 9 was the anniversary of the birth of George Stephenson. It was sometimes claimed that George Stephenson was the inventor of the locomotive; he had not invented the locomotive, but he was certainly the engineer who had made railways a commercial and practical proposition in this country and throughout the world, and perhaps that was an even greater achievement than the invention of the locomotive itself.

Whilst one did not wish to seek consolation from the greater difficulties of other people during these times of depression, the Deputy Lord Mayor pointed out that there were some factors in the world which gave us some comfort. In the first place, the Government of Germany was in a very precarious position, whereas

we had a Government with a great majority, and which was really a Government. Again, the United States were in great difficulties, the South American republics were in bankruptcy, and there were difficulties in other countries throughout the world. We were paying not only our own debts but also the debts of other peoples. So that there was not so much for us to worry about.

Commenting on the success with which new industries had been developed in Newcastle, he said that when visiting the Commercial Motor Vehicle Exhibition in London a few months previously he had been greatly impressed by the exhibits of the wonderful new Armstrong motor vehicles using heavy oil, and by the remarkable number of orders which had been booked for those vehicles. As representing the city, he took the opportunity to wish this enterprising firm every success in their efforts to bring back prosperity to this district and to the country as a whole. Finally, he said that other encouraging factors were that the bank rate was down to $2\frac{1}{2}$ per cent., that to all intents and purposes there were no strikes in this country.

The Sheriff of Newcastle, who also responded to the toast, mentioned that one of the buildings which had formed part of the North-East Coast Exhibition of 1929, on the Town Moor at Newcastle, had been retained and would be utilised as an industrial museum; it was to contain relics of past achievements in the development of metals to the requirements of civilisation. Newcastle, he continued, had benefited by its Stephensons, its Armstrongs and its Parsons, but it had no desire to be satisfied with past achievements, and new industries were developing there. Since he had had a short run on the Diesel-electric unit, built by Messrs. Armstrong, and running on the West Line of the London & North Eastern Railway, he had wondered whether that unit was to be the forerunner of another railway revolution. There was no doubt, however, that Britain would be among the first of the nations to revive its

industries, and certainly would survive; he hoped that when that time came the Tyneside would play an important part.

A Dual Mentality.

Professor Henry Louis, M.A., D.Sc., A.R.S.M., proposing the toast of "The Institute of British Foundrymen," said he accepted the task with very great pleasure, not only because he knew that the toast would meet with a cordial and enthusiastic reception, but also because, although his own experience of foundry work was not a very long one—and he was sorry to say that it had occurred over half a century ago—it had nevertheless left him with a very sincere admiration for the work of the foundrymen. He had realised at a very early stage that a successful foundryman must combine two different and, in some respects, even opposite mentalities, because the man who prepared the mould must be, and was, an artist, and the man who prepared the metal to pour into the mould must be a scientist. It was rather difficult to combine those two somewhat opposite qualifications. We all knew that the British moulder was a thoroughly skilled man, and he was perhaps one of the few representatives left of the old British handicraftsmanship. He had the artist's trained hand and trained eye for his work. That quality was derived to some extent, of course, by practice, but to a large extent also it must be inborn, and, as we liked to think, inherited from generation to generation.

The foundryman's art was very ancient indeed. Reference had been made to the ancient city of Newcastle, but Newcastle was a mushroom, a growth of yesterday, compared with the foundryman's art. Those who had seen some of the beautifully cast-bronze spearheads of what archæologists called the later Bronze Age would agree that the production of such beautifully cored castings, with their very thin and uniform walls, would tax a good many foundrymen today. The inherited skill of hand and eye was

important to the foundry trade. Since he had been engaged in the foundry a great deal of manual work had been replaced by machinery. In his day there were no pig-casting machines, no jolt-ramming machines, and so on, but he was convinced that, in spite of the changes that had been made, the skilled hand of the workman was as important to-day as ever it was, and he was fully convinced that our men could hold their own with any others.

For centuries, for æons, foundry work had been concerned entirely with bronze and brass casting. Then, about the 15th century, the art of iron founding was practised. It had originated in Central Europe, but had very soon reached this country, and before very long our ironfounders were able to teach their teachers. It was quite well known in the Middle Ages, throughout what was then the whole civilised world, that the English cast cannon were superior to any other cannon, and all the other nations had come to us for their cannon. Indeed, he had very often wondered whether the great men whose names had been handed down in history, the great sea Captains of Queen Elizabeth's time, did not owe a great deal of their triumph to the obscure Sussex ironfounders who had cast their guns. Be that as it may, he was quite convinced that the foundry industry would continue to flourish, and if the industry continued to flourish, then the Institute would flourish with it. We were living in an age of change. He did not say that we knew very much yet, but we had gained far more knowledge of the constitution of metals than we had possessed half a century ago, and our foundrymen were making full use of that knowledge. The Institute was keeping foundrymen throughout the country in touch with all the most modern developments.

The work of the President, Mr. Stobie—whose name he coupled with the toast—lay more especially in the highly modern branch of steel founding, which had had to develop practically a new technique, certainly within his (Prof. Louis')

lifetime. Probably he had had a hand in some of the earliest steel castings ever made in this country, because he had been concerned, about 1880, with the casting of shoes and ties for some of the tin stamps direct from the open-hearth furnace at Landore, and he ventured to think that they were the first steel castings ever made in this country. Mr. Stobie had improved steel practice very greatly, however. He had devised several admirable electric furnaces for melting the steel, and thus was helping forward that branch of the industry.

Finally, Prof. Louis added the opinion that the founding industry would have to change its character somewhat. There was no denying that our heavy industries were in a parlous condition, and he was inclined to think that the future of founding in our country lay in lighter and higher-class work. He had not the slightest doubt, however, that the British foundryman, helped by his Institute, would rise to the occasion whenever necessary and would be able to produce the highest-class work that could be desired.

The PRESIDENT prefaced his response by a further reference to the high-level bridge at Newcastle, mentioned by Col. Ionides. There was a good deal of stress and tension in that bridge, he said, and he believed that within the cast-iron hollow cylinders there were various rods of wrought iron. Coming to the remarks of Prof. Louis, he said that perhaps Prof. Louis had thought—and it was excusable—that the members of the Institute were more concerned with the art of foundry than with the science of foundry. As a matter of fact, however, they were equally concerned with both, for there were within the Institute academic gentleman of great renown, such as Sir Harold Carpenter and Prof. Turner, great industrialists such as Lord Weir and Sir Robert Hadfield, some of the best-known metallurgical works technologists, and, as fully equal brethren, those experienced in the art rather than the science. In all branches there were men who had been apprenticed to the trade

and had done the work on the floor, and men with university experience, and some of them had had both floor training and university experience. Therefore, although the Institute's name suggested that it was concerned purely with the artists, it also claimed to embrace within its membership the scientific technologists. The Newcastle Branch had had the pleasure of receiving Papers from Armstrong College, where Prof. Louis was at one time Professor of Mining and Metallurgy.

After some amusing references to events which had occurred during his student days at Sheffield University, Mr. Stobie commented upon the industrial situation, and said that founders were awaiting anxiously the revival of a modicum of shipbuilding and engineering which would enable them to apply the wonderful developments which had been made in their science in recent years. They would then be able to prove that the hopes and aspirations which they expressed on occasions such as this were not empty words.

Mr. W. Scott (Senior Vice-President, Newcastle and District Branch of the I.B.F.), in an amusing speech, proposed the toast of the guests, and extended to them all a hearty welcome. In the course of his remarks he made particular reference to the ladies, and suggested that the Newcastle Branch might invite the ladies to some of its meetings.

Mr. E. J. George, responding, thanked the Institute for its charming hospitality, but added, amid laughter, that he was not sure that he took such delight as did the members of the Institute in the fact that they were scientific. Those who tried to sell to them had a notion that they had got on better when the buyers were less scientific. One would think that science would teach them to know what they wanted, but the more science they acquired the less sure they became that they had what they wanted, or the more positive were they that they had not got it. He was glad that there lingered among them, however, some remnant of the old brigade. One felt so happy when one sent to an individual in a provincial

place something which that individual pronounced to be good. However, said Mr. George, he would not criticise his hosts too much, except to suggest that they should not become much more scientific, or it might be impossible for those who supplied them with goods to live with them. (Laughter.)

Though he did not wish to discuss at length the industrial situation, Mr. George reminded the gathering that the tide turned at low tide as well as at high tide; he believed it would turn, and was sure that both the hosts on this occasion and their guests would join together to assist it to turn. We ought not to despair. Not even the most pessimistic, even before dinner, and certainly not after dinner, could be guilty of thinking that the tide would not turn, and turn for the better.

Finally—in a reference to the visit which the members of the Institute were to pay to the Consett Ironworks on the following day, he said he hoped to show them the whole place at work. He would not say how far the work had been saved up—(laughter)—but he pointed out that work had never ceased there for a whole week at a time, and it was something to be able to say that. They had always carried on, even if there were only a shift or two. (Applause.)

Vote of Thanks to Executive Committee.

After the discussion of Papers on Thursday morning, the members again were invited to luncheon at the County Hotel, Neville Street, and before they left for the afternoon visits to works, the PRESIDENT proposed a most hearty vote of thanks to the five knights of the Executive Committee—whose names were mentioned earlier in this report—for the excellent manner in which they had arranged the programme. The smoothness with which the programme had worked indicated how perfect had been their organisation. (Hear, hear.) If foresight were not exercised in the whole of a hundred directions, the odd one-hundredth would spoil the enjoyment of those taking part. The members

of the Committee had had to collect the necessary money, the arrangement of the Papers presented had been a big job, the arrangement of works visits had called for diplomacy, and the catering was a matter calling for good taste. He personally thanked the Committee for having almost done his job for him. The Souvenir Booklet which had been produced was a most excellent production. The President took the opportunity to thank the Ladies' Committee, and finally paid a special tribute to Mr. Eckford, the Hon. Secretary, whose work had been prodigious.

Mr. John Cameron (Past-President), seconding, recalled that when engaged in commercial travelling, in his young days, he had visited Newcastle on many occasions, and had found it to be then, as now, one of the most pleasant places to come to. There was a warmth of hospitality and generosity among the people of Newcastle, and the charm of the place had impressed itself very strongly upon him. The present visit had served to emphasise it. Many of the members would recall the high standard which Newcastle had set on the occasion of the annual conference held there in 1924; it was a standard of perfection which had taken the Institute by storm. At that time Mr. Patterson was President, and Mr. Colin Gresty, who was then hon. secretary, and Mrs. Gresty, had done a great deal of work. This year Newcastle had again entertained the Institute magnificently, and the members were indeed grateful.

The vote of thanks was carried with enthusiasm.

Mr. J. W. Eckford (hon. secretary), who was greeted with prolonged applause, responded. He recalled that Mr. R. J. Shaw, who had been hon. treasurer of the Committee, had accepted a post in Coventry during the course of the work, but Mr. Colin Gresty, the chairman of the Committee, had kindly stepped into the breach and had carried out the duties of hon. treasurer as well. Mr. Eckford also expressed thanks to the President, who, at great inconvenience, had

attended meetings at which vital decisions had had to be made. The guidance of Mr. Makemson, the Secretary of the Institute, had also been most invaluable.

Finally, Mr. Eckford assured the members that the greatest satisfaction of the Committee was the knowledge that the members of the Institute had enjoyed their visit.

Thursday, June 9.

The Conference was resumed at 9.30 a.m. in the Lecture Theatre of the Literary and Philosophical Society, Mr. Victor Stobie, President, presiding.

Dr. W. Rosenhain, F.R.S., presented his Paper on "Ferrous and Non-Ferrous Metals in the Foundry," which was then discussed.

The meeting then resolved into Sessions A and B, Session A being held at the Literary and Philosophical Society under the chairmanship of the President, while Mr. C. E. Williams, Senior Vice-President, presided over Session B in the Bolbec Hall. Reading and discussion of the Papers then proceeded as follows:—

SESSION A.

"Hardening Cast Iron; Hardened and Tempered and Nitrogen-Hardened Cast Iron," by J. E. Hurst, Sheepbridge Stokes Centrifugal Castings Company, Limited.

"High-Test Cast Iron in the United States," by R. S. MacPherran.—(Exchange Paper presented on behalf of the American Foundrymen's Association.)

"Distortion and Camber in Castings," by E. Longden, Craven Bros., Limited, Manchester.

[Mr. Longden was suffering from a severe burning accident to his foot and was loudly applauded by the Conference when he rose to introduce his Paper.]

SESSION B.

"Some Lifting Consideration in a Jobbing Steel Foundry," by F. J. Hemming, F. H. Lloyd & Company, Limited, Wednesbury.

(This Paper was presented on behalf of the author by Mr. R. Wilson.)

"A *résumé* of the Work of the Malleable Iron Sub-Committee of the Technical Committee," presented by Mr. J. W. Gardom, Convener of the Committee.

Upon the adjournment of the Conference at 12.30 members lunched at the County Hotel.

After lunch the President proposed a vote of thanks to the Conference Executive Committee for their excellent work in preparing the Conference and for all the excellent arrangements which had been made. He also thanked the Ladies' Committee and paid a special tribute to the work of Mr. J. W. Eckford, the Conference honorary secretary.

In seconding the vote of thanks, Mr. J. Cameron, Past-President, referred to the well-known hospitality of the people of Newcastle and expressed appreciation of the magnificent work of the Conference Committee. The vote of thanks was carried with enthusiasm.

Mr. J. W. Eckford responded and paid a tribute to the work of his fellow members of the Committee.

Parties of members visited the works of the following firms during the afternoon:—

Consett Iron Company, Limited, Consett.

Armstrong-Saurer Commercial Vehicles, Limited, Scotswood.

Smith, Patterson & Company, Limited, Blaydon-on-Tyne.

Sir W. G. Armstrong, Whitworth & Company (Iron Founders), Limited, Gateshead-on-Tyne.

Civic Reception and Dance.

On Thursday evening, June 9, members of the Conference and ladies were invited to a reception

and dance given in the Old Assembly Rooms by the Lord Mayor and Lady Mayoress of Newcastle-upon-Tyne. In the absence of the Lord Mayor the guests were received by the Deputy Lord Mayor, Councillor Crosby, and the Deputy Lady Mayoress, the Sheriff, Councillor Leadbitter and Mrs. Leadbitter, and the President of the Institute, Mr. Stobie.

The beautiful suite of rooms is an ideal place for a function of this kind, and the wonderful floral decorations added very much to its attractiveness. The guests passed into the large dance hall and the proceedings opened with what to many was a novel function. A troupe of pipers in full Highland costume, lead by a Pipe Major, paraded the hall, and were followed by the Deputy Lord Mayor and Deputy Lady Mayoress, the Sheriff and his wife, the President and Mrs. Stobie, and all the guests fell into the procession, which perambulated back and forward along the great hall. Thus stimulated, the feeling of lukewarmness which sometimes marks such functions at the outset was immediately dissipated, and the guests joined in the dancing enthusiastically.

Later in the evening the pipers again appeared, and members of the troupe gave exhibitions of Highland dancing. Refreshments were served in an adjoining room.

When the guests departed at 12 p.m. it was their unanimous verdict that this was one of the jolliest and most successful functions of its kind that had ever been their privilege to participate in, and there were many expressions of appreciation of the wonderful hospitality of the hosts.

Friday, June 10, the closing day of the Conference, was given over to an excursion by motor coach. About eighty members and ladies left Newcastle by the long straight road to Hexham, which follows the line of the Roman wall and in many places is on the actual site of the wall itself. Glimpses of the wall were seen from time to time, though it is understood that the best preserved portions are further west.

The Roman wall was built by the Emperor Hadrian about A.D. 120, and stretches from Wallsend-on-Tyne to the Solway, a distance of 73½ miles. At each mile a milecastle was built, and at intervals of every four miles was a station to accommodate the garrison.

A halt was made at the camp now known as the "Chesters," or Roman Cilurnum, about 24 miles west of Newcastle. The camp has been fully excavated, and the visitors were able to inspect the barracks for the accommodation of the troops, the remains of the regimental chapel, the strong room and the Commandant's house. There were elaborate systems of drainage which are still well preserved, and the quarters of the Commandant were provided with central heating. Many notable treasures which have been discovered in the excavations have been moved to a nearby museum, which was also inspected. From Chesters the party proceeded to Hexham, where lunch was served at the Hexham Hydro. After lunch, Mr. James Smith, President of the National Ironfounders' Federation, proposed the health of the ladies, which was responded to by Mrs. Victor Stobie.

The journey was then resumed over wild moorland scenery to Otterburn, where another halt was made to permit of inspection of the Old Woollen Mill. The mill was taken over in 1821 by one Wm. Waddell, and produces tweeds of various kinds which are famous all over the world. The only wool which is used in that which is obtained from local sheep bred in the neighbouring Cheviot Hills. Of particular interest were two specimens of hand looms which are still in daily use, producing wonderful examples of modern fabrics. The whole process from the raw wool to the finished article is carried out on the premises, and the mill is a rare example of a self-contained and comprehensive industry whose work is permeated by the spirit of old time craftmanship.

From Otterburn the journey was continued over the moors to Rothbury, a charming country

town and holiday resort well known to Tynesiders. After tea at the County Hotel, Rothbury, the party returned to Newcastle-upon-Tyne by way of Morpeth. On arrival at Newcastle the "good-bye's" and "see you next year's," which are inseparable from all Conferences, took place, and thus ended a very happy and enjoyable last day of a very successful Conference.

PAPERS PRESENTED AT THE NEWCASTLE-UPON-TYNE CONFERENCE.

QUANTITY PRODUCTION OF GREY-IRON CASTINGS.

By J. O'Sullivan.

An event of outstanding interest to foundrymen is, undoubtedly, the opening of the Ford foundry at Dagenham. The Cork foundry of Messrs. Henry Ford & Son, which has been in existence for the last twelve years, cannot claim to be as modern as the foundry at Dagenham will be, but the processes developed in the River Rouge plant at Detroit and Cork are the foundations upon which the Dagenham foundry has been designed. Though the methods of quantity production will be familiar to many, yet the synchronisation of these methods may present some new angles, and, therefore, it is proposed to concentrate on the sequence of operations rather than to present a detailed account of them. The chart (Fig. 1) is intended to illustrate the synchronisation employed and its skeleton forms the basis of this Paper.

Laboratory.

After having passed inspection by the laboratory, the incoming bulk raw materials, embracing pig-iron, coke, scrap, sands, clays, are loaded into conveniently-situated storage bins; whilst the less bulky commodities, such as core wire, blacking, soluble starch, binders, oil and other incidental foundry materials are put into stores, from which they are withdrawn only against a signed requisition.

Cupola Plant.

The night gang come on at ten o'clock to prepare the cupolas for the next day. This gang

remove the dump, chip and patch the cupolas and have everything ready for the charging gang, a portion of which starts work one hour before the moulders arrive. Charging is all done by hand in the following sequence: Coke, limestone, steel, pig-iron, borings, scrap and ferro-silicon. The cupolas are level until sufficient charges to complete the day's work are consumed.

Equipment.

The wheelbarrows used on the charging floor are of a standard type; they are well balanced and of the same weight and capacity. The scales used, of which there are four, are of spring-balance, large-dial type, so that one can easily observe that the correct weights are used, without standing near the scales. The composition of the different charges is supplied by the laboratory, which department also fills in the charts which are hung up on a blackboard. On this there are also marked up the number of charges put into the cupolas every hour. Pig-iron is conveyed to charging floor by a conveyor, the scrap and limestone by a crane and the coke from overhead bunkers. These bunkers are filled direct from cargo steamers by a 5-ton transport and grab.

There are seven cupolas (Fig. 3)—three of 60-in., three of 56-in. and one of 42-in. internal diameter and of standard make; they are all fitted with both volume-recording and pressure gauges. Once the blast is put on the furnace, it is run to a determined capacity, and the board on the charging floor should show a regular number of charges hourly. This is considered essential if the metal is to be kept within specification and machine-shop expectations are to be fulfilled.

The compositional tolerances of the irons are specified at T.C. 0.3, Si 0.3, Mn 0.2, S 0.1 and P 0.04 per cent. Silicon determinations are made hourly, whilst complete analyses of all metals are made at least once daily. The laboratory controls the temperature at which the metal

is poured. The first tap of iron is invariably pigged, together with any surplus, into a pig-casting machine-conveyor, which returns it up to the charging floor. The liquid metal is conveyed by a mono-rail from the cupola spout to the various pouring stations (Fig. 5).

Core Shop.

Core Wash.—The care of all washes is undertaken by one man who mixes and maintains the stocks. Great care is devoted to this particular, because, if the materials are faulty or incorrectly mixed, much trouble will be encountered in the cleaning of the castings. What is desired is a mixture that will dry on the core without cracking, will withstand the wash of the metal, and finally, when mixed, will remain in suspension. All washes are kept agitated when in use; they must conform to certain Baumé numbers, usually 23 or 46, and their correctness is frequently checked by the foreman, as well as the man making the wash. Core wires are cut and bent on automatic wire machines and supplied in bundles to the core makers.

Sand.

There are in use no less than 14 different mixtures of core sand and three washes. Core sand is mixed on the first floor in four revolving-paddle-type mixers. Sand is first measured into the mixer and oil or other bonding material, such as soluble starch, is added. When mixed it is dumped through a grating in the floor, which feeds a shute terminating immediately above one of the core maker's tables. This is shown in Fig. 6. As far as possible the same men are always retained for the work of sand-mixing.

Particular attention is paid to the green-bond strength of the sand. If the sand is insufficiently or over-mixed the green bond will be weak. A board, with the mixtures painted on it, is hung up in the room for the men to work from, and no one except the executive is allowed to change any mixture. Continuous application enables these men to become expert at this work, and

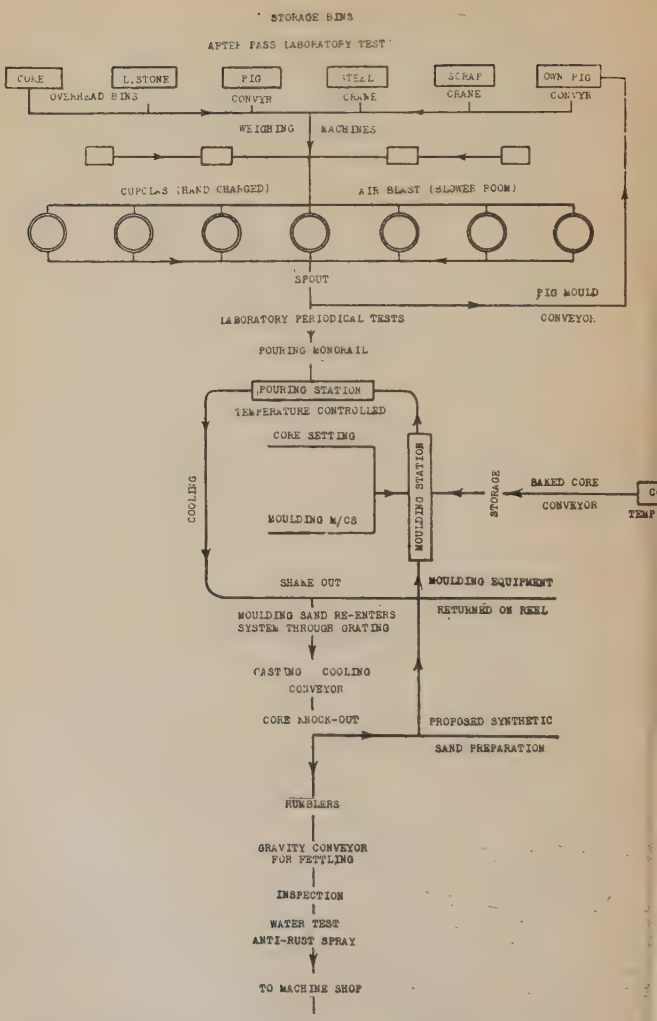
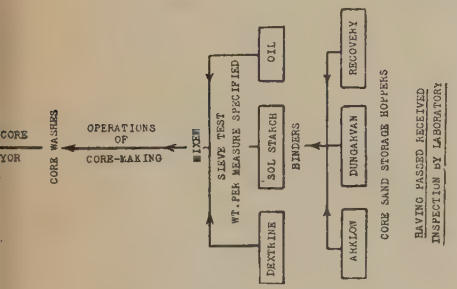


FIG. 1.—CHART INDICATING THE NEED FOR SYNCHRONISATION IN QUANTITY PRODUCTION.

the result is a very uniform mixture of core sands.

Three kinds of sand are used as raw material in the core shop, a sharp sand or sea sand (99 per cent. SiO_2) and bank sand (90 per cent. SiO_2) and a small amount of recovered core sand. A well-selected, properly-mixed core sand will eliminate the use of wires and vents in many types of cores, whilst stripping cleanly from both the core box and the castings, with a consequent increase in production.

A point worth mentioning is that core wires can to a considerable extent be eliminated by



the use of a core sand with a high green-bond strength. This type of core sand is readily obtained by the use of a mixture consisting of a soluble starch compound and dextrines. To this is added a small portion of oil. The oil addition, while it adds nothing to the green-bond strength, enables the finished core to be stored more satisfactorily.

Core Boxes.

All core boxes are of metal and accurately machined, as also are the core plates and shell carriers. Wires are used very sparingly and only where necessary; vent wires are used in a very few cores.

Some men complete the boxes by themselves. Other cores are made by a gang working around

a circular table. The making of the core is then split up into several operations. Depending on the class of core, the gangs will sometimes comprise three, four or five men to a table. These

Fig. 2.—Cupola Charging Floor. Messrs. Henry Ford & Sons, Limited.

men just make the core and turn it into drier, where it is stamped with the shift stamp. It is then sprayed or dipped and placed on the green-core conveyor to be stoved. This is shown in Figs. 6 and 7.

One great advantage of the gang work is that the operations of making complicated cores is split up, and a man very quickly learns to perform the particular operation he is called on to

FIG. 3.—SHOWING THE CUPOLA PLANT. THERE ARE SEVEN FURNACES WITH DIAMETERS VARYING FROM 60 TO 42 IN.

do. It is also easier to instruct a new man, or to replace a man who is away through illness or other cause. Another advantage of gang labour is that a new man working alongside an old hand gets familiar with the real operation.

and as a rule becomes proficient quickly when called upon to do so. Further, every man is anxious to get his particular operation on the core finished and passed along to the next operator. Of course, a new hand slows the job

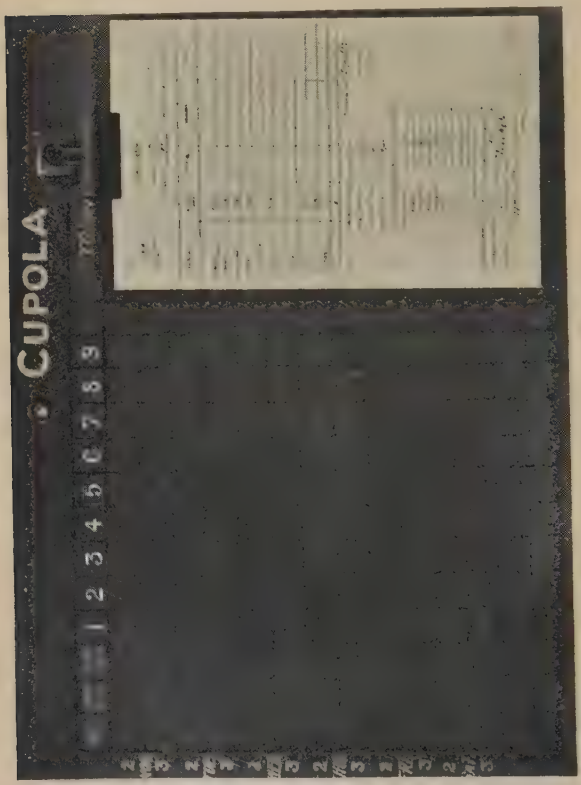


Fig. 4.—A Black Board shows how Practical Working is Related to the Daily Control Charge Sheet.

up a little until he is competent, or a naturally-slow man will have the same effect, but when he finds the operator behind him is waiting for the core box, and the man in front of him puts his core box up against him, he soon rises to the

occasion and is just as keen as the rest of the gang to keep his section of the work moving

Form 131

CUPOLA CHARGES

2nd Shift Cupola No. 5 Date Feb 1st

Grade Iron "A" No. of Charges 53.

MATERIAL	WT. PER CHARGE	CHARGES	REMARKS	TOTALS
HEMATITE	Nil			
FOUNDRY	800			
"A" SHOP SCRAP	800			
BORINGS	300			
FOREIGN SCRAP	/			
STEEL	500			
FE. MN.	10			
FE. PHOS.	/			
FE. SI.	10			
COKE	290			
LIMESTONE	100			
FLUX	2			

COKE:- BARROWS IN CHARGE 1 53 CHARGES AT 290 lbs

EXTRA BARROWS IN CHARGE 2

BARROWS IN BED 11

TOTAL BARROWS 56

FIRST FIVE CHARGES - MORNING AND AFTER LUNCH

ALTER HEMATITE TO:-

Foundry	700
Shop Scrap	900
Borings	300
Foreign Scrap	/
Steel	500
Fe. Mn.	10
Fe. Phos	/
Fe. Si.	5

80% Powdered Ferro Manganese Used / LBS.

50% Powdered Ferro Silicon Used 25 LBS.

Cupola/Repair:- 32 Bags Plastick

Tapping Bricks /

FOREMAN John L. Sheehan

FIG. 4A.—DETAILS OF THE CHARGE SHEET INDICATED ON FIG. 4.

freely. The last operator places the core on the green-sand conveyor. All cores are checked and production is marked up hourly.

Cores are taken off the green-core conveyor and placed in the core ovens (Fig. 8). Core plates and shell driers, when stripped of cores, are returned to the core makers by the green-core conveyor. The ovens are of the continuous

Fig. 5.—Overmetal is Poured into a Conveyor made up of Chill Moulds, which Returns the Resultant Pigs to the Charging Floor.

type, heated by gas and are controlled by recording pyrometers.

Some cores are dipped green in the following manner:—Gear-case cores, together with their plates, are plunged into the wash. Barrel cores

are placed on a revolving pendulum-type stand, of which there are four to the machine. The stand is turned through 90 deg. which brings a section over the wash tank shown in Fig. 7. The tank is then lifted by a compressed-air cylin-

Fig. 6.—Core Sand, prepared on the Floor Above, is delivered by Shutes to the Tables shown on the Left. Green Cores are made and placed on the Pendulum Conveyor.

der, and so submerges the core. The tank is now lowered and core is stored in the usual manner. Others are sprayed whilst on the dried-core conveyor, where dry cores are taken from oven and put on the dried-core conveyors leading to the

core assembly. In the case of jacket cores, they are rubbed and fitted, assembled and finally inspected and placed on the storage conveyor which also carries the cores to their respective moulding conveyors.

Moulding Floor Systems.

The moulding department consists of a jobbing shop where patterns and the general equipment used in the plant are made; and three con-

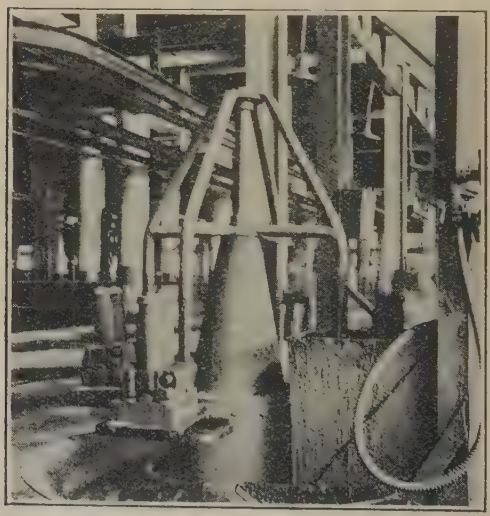


Fig. 7.—Core-Washing Apparatus.

veyor systems—two of the drag and one of the reel type. One of the drag conveyors, on which the large tractor castings are made is equipped with power-jolt rollover machines, and its capacity is upwards of 2,800 moulds in eight hours. It operates as follows: On the outside of rails which run in the direction of the pouring stations, the drag, or bottom-half of the mould is carried slowly forward, and the men

engaged on core-setting, place in the cores and gauge them. By this time, the mould has reached (Fig. 11) the position where the top-half of mould is made and finished ready to close and complete the mould. The mould is then

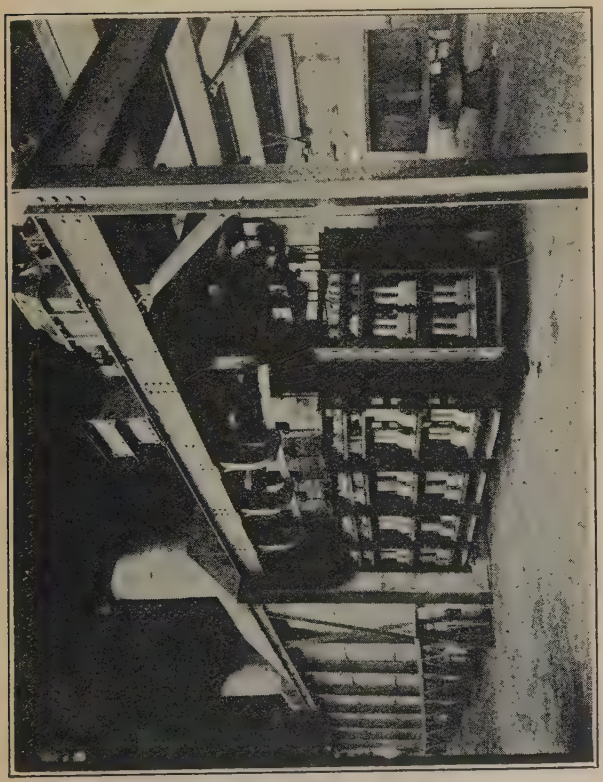


Fig. 8 shows the Continuous Core Oven Used.

closed, clamped, and heads made up by the time the pouring station is reached, metal is poured and mould is transferred to the centre set of rails which travel in the opposite direction to the outside sets. The moulds are taken

down to the shake-out, where a chain conveyor conveys the castings to the cleaning department. The sand is tempered and the flasks are returned to the machines.

One of the features of the conveyor systems

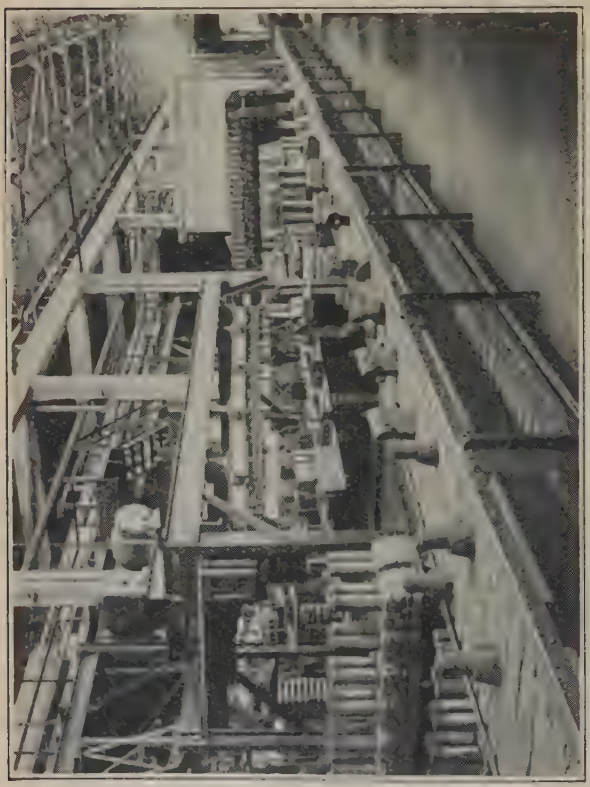


Fig. 9.—The Dried Core Conveyor.

is that all operations must be synchronised if the fullest benefits are to be obtained, and one of the most important—if one can be more important than the other—is the pouring station. When the mould has reached this

point, the metal must be there ready and waiting. Of course this does not mean too early or else it will become cold and be useless, and if late the conveyor has to wait, which means that

Fig. 10. A Pendulum Conveyor serving the Pouring Section.

production will be impeded, as there is no available room for the moulding operators to place the moulds except on the conveyor.

The Reel System.

The reel system comprises of two pendulum-mould conveyors (Fig. 10) with an accompanying

sand system with a capacity of 4,800 moulds in eight hours. The machines used are of hand rollover and power jolt squeeze and strip type.

The method of dealing with the sand is

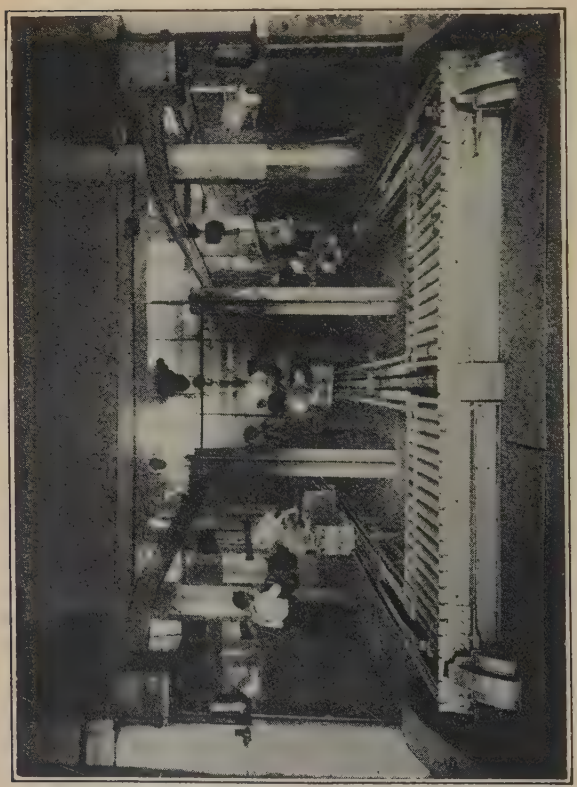


Fig. 11.—For Heavier Moulds a Drag Conveyor is used for Serving the Casting Section.

similar to the drag conveyors. The number of men working in a team on the reel is naturally smaller than the drag, usually between 4 and 8, depending upon the type of machines in use. The system operates as follows:—The man

working upon the drag makes the mould, rolls it over on a revolving stand, which turns one quarter of a revolution and also brings an empty flask directly to hand. The second man places in a core, if called for, and puts drag

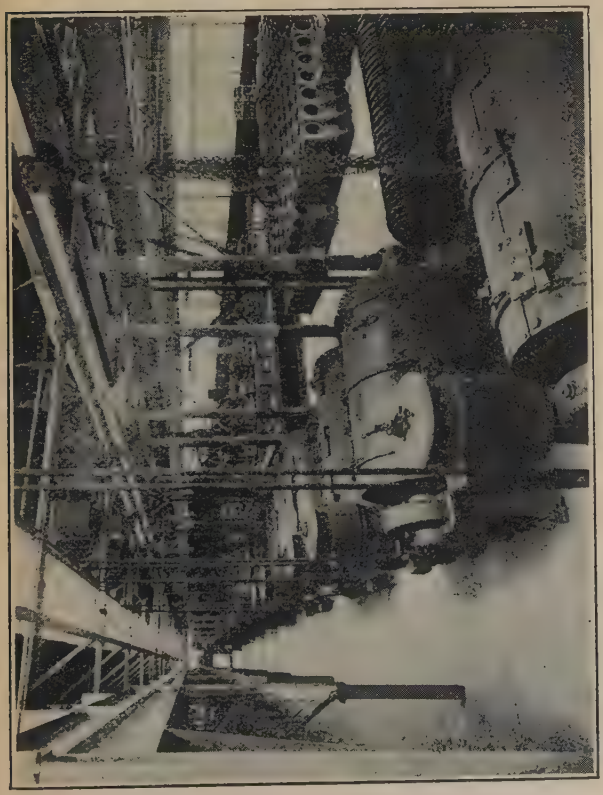


Fig. 12.—Tumbling Barrels are Used for Cleaning Quite Complicated Castings.

half of mould on to the reel. He also places the empty flask on the stand ready for the moulder and has the bottom board handy. The third man makes cope moulds and places them on a similar stand ready for the fourth man,

who cleans out runners, completes operation by closing the mould, putting on mould-weight and checks the number made. The mould is then cast and shaken out and flasks are hung

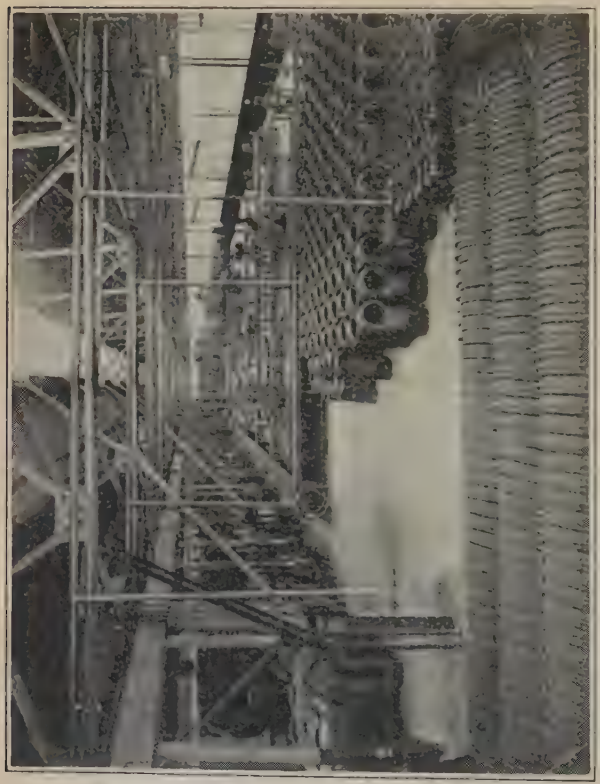


Fig. 13.—After Cleaning Roller Conveyors are Used for Despatching the Castings.

on the conveyor. The castings are then inspected and placed on the casting conveyor for transport to the cleaning department.

When the castings have passed the core knock out, they are then loaded in tumbling barrels and tumbled (Fig. 12). They are once more

inspected and defective castings are sent to salvage department. Good castings travel on conveyors to be ground (Fig. 13). If they have to be chipped then men with air-chisels standing at each side of conveyor do necessary operations. Castings that require it, have their core wires extracted and are then hydraulically tested and finally inspected.

Scrap.

All scrap that arises during the course of manufacture has to go through salvage department, where it is sorted out and numbered according to a corresponding number on the scrap report for the various defects, and placed in their respective pile and painted. This also includes scrap return from the machine shop for foundry defects. At 10 o'clock each morning all the foremen, having been in possession of their scrap report earlier in the day, meet and examine the scrap pile. Reasons for its existence are agreed upon and the steps to be taken to eliminate the causes are discussed. In addition, the foremen are appraised during the daily operations. For instance, if the inspector at the shake out picks out a defective casting, he immediately acquaints the foreman on the line, and core room foreman and man in charge of pouring the metal are brought together on the job if necessary. Of course, at this stage it is only a rough inspection but its value lies in the fact that in less than ten minutes after the mould is cast, if the casting shows a defect, it is immediately traced to its source. The same system applies when scrap is picked out later, and then the cleaning room foreman does not forget to keep them posted as to how the work is going through so that by the time the daily general inspection of scrap comes, steps have already been taken to remedy the defect. Defective casting that can be salvaged are put through the reheating furnace, welded, and then either passed or finally scrapped. No scrap is accepted on the charging floor unless painted.

A reference to Fig. 1 shows the converging of all operations at the pouring station, and before concluding the Paper we wish again to emphasise the importance of accurate timing at this point. Irregular service from the cupola will mean a shortage of metal or an over supply of metal. The former will hold up the moulding operations, the latter will result in cold iron and mean the pigging of this metal. Irregular production in the moulding will result in the same sequence of effects as an irregularity in the metal supply. As a concluding remark, it seems appropriate to state that never has the adage "Time means Money" been more applicable than in the quantity production of grey iron castings.

DISCUSSION.

Mr. B. Hird, referring to the limits of composition of the irons, asked if they represented the maximum extent to which the analyses of the various irons were allowed to vary, and that the variation of phosphorus content, for example, was not more than 0.04 per cent.

Mr. O'Sullivan replied that the phosphorus content of and composition, for example, was specified to be within the limits of 0.18 and 0.21 per cent.; in another composition the limits specified might be from 0.27 to 0.33, and in another from 0.34 to 0.37. Again, a specification might call for a silicon content within the limit of from 1.8 to 2.1 per cent.

Mr. Hird asked whether the irons were hematite or ordinary foundry irons.

Mr. O'Sullivan replied that he used a hematite and a foundry iron; it was all iron to him, so long as it met the specification. The Company bought to specification, and they bought preferably a machine-cast pig-iron if it could be obtained.

Organisation and Production.

Mr. J. W. Gardom said he had had the privilege of taking a party of foundrymen over Messrs. Ford's works at Cork. As a friend of

Mr. O'Sullivan, he could criticise the paper, and candidly he was disappointed with it, because it did not give, to those who had not seen the works, any idea of the organisation there. Recently he had had the privilege of speaking to the manufacturer of one of the best moulding machines, other than British, and had said that he was surprised by the production that the Ford Company could secure with their machines. The manufacturer had replied that the Ford Company could get 20 per cent. more than any other firm. That, said Mr. Gardom, indicated organisation, and Mr. O'Sullivan was responsible for it. When one got into the foundry one could not see any organisation, and he was hoping that the paper would have told him how it was done.

Commenting on the reference in the paper to the core-making gang, and the statement that when a new member of the gang, or a naturally-slow man, found that the operator behind him was waiting for the core-box, and that the man in front of him put his core-box up against him, he became just as keen as the rest of the gang to keep his section of the work moving freely, Mr. Gardom confirmed that the men were really keen. It might be thought by some that in a production foundry the men were not keen, but were driven; his experience of the Ford Company's foundry, however, confirmed that the men were keen and were really anxious to secure output. He did not think this fact was usually accepted, and was glad, therefore, that Mr. O'Sullivan had mentioned it.

With regard to the limits of composition of the irons, Mr. O'Sullivan had stated them in a new way. Limits and tolerances were often given as "Plus or minus," and he asked if the figures meant that if, for instance, the total carbon content was specified as 3 per cent., the actual content could vary from 3.0 to 3.3, or whether it was permissible for the total carbon content to vary from 3.3 down to 2.7.

Finally, he asked how the moisture content of the sand was tested. It was stated in the

paper that the men became very expert in keeping their mixtures uniform within very close limits, but it would be interesting to hear how Mr. O'Sullivan assured himself that they were uniform.

Sand Moisture Testing.

Mr. O'Sullivan replied that in most cases a total carbon content of from 3.2 to 3.5 per cent. was specified, and it must be within those limits. If not, one did not get the finish on the castings, and complaints were received. If the silicon content were one point over the amount specified, the same applied. His experience had been that the total carbon content was really controlled by the operation of the cupola. There was a sand-testing machine in use at the Cork foundry, and it worked very well in practice. It was supplied by an American firm, the Federal Foundry Supply Company. Tests were made periodically with this machine, and evaporation tests were also made, and the two tests checked up very well. It was the practice to have one man engaged wholly on the mixing of facing sand, and there was another man engaged solely on the tempering of sand. The sand came through regularly, and the man became so accustomed to controlling the shake-out and the sand coming through that he regulated the water supply well. There was very little trouble with regard to moisture.

Mr. V. C. Faulkner (Past-President) said he had noted at the Cork foundry and at one or two very large quantity-production foundries in England, that one man had his hands in the sand all day long, and it seemed to be a reflection upon the scientists that they could not evolve an instrument which would indicate the moisture content.

Mr. O'Sullivan considered that the present method was the best under the circumstances. The man who had his hands in the sand all day could regulate the percentage of moisture to within 0.5 per cent. or less, as had been proved time and again.

Low Phosphorus Irons.

Mr. F. J. Cook (Past-President), discussing the limits imposed with regard to the various elements in the iron, said he agreed that some limits should be imposed, but the point that astounded most British foundrymen was that the variation of phosphorus content must not be greater than 0.04 per cent. The limits seemed so small, and he asked why such small limits were arrived at.

Mr. O'Sullivan said that in one class of iron the phosphorus content called for was from 0.17 to 0.22 per cent. in the casting.

A Member pointed out that the limit of variation in that case was 0.05 per cent.

Mr. O'Sullivan added that sometimes the phosphorus content might be specified as from 0.27 to 0.33. It depended on the class of work to be done. All the irons used were of low phosphorus content.

Mr. B. Hird suggested that with a phosphorus content of 0.17 per cent. one was approaching the danger point in respect to fluidity. If the phosphorus content were below that figure, difficulty might arise due to the iron eating into the sand where it formed sharp projections in the mould. He asked if difficulty had been experienced at Cork in that respect, due to too low a phosphorus content.

Mr. O'Sullivan said he had seen irons with phosphorus content as low as 0.15 per cent. Of course, troubles were experienced at Cork, as everywhere else, and such troubles as did occur due to the metal eating into the sand were experienced mostly in the cores. He believed, however, that this was due more to insufficient ramming than to the metal.

Msoiture Control and Limestone in Cupola Practice.

Mr. F. Hudson, commenting on Mr. Faulkner's remarks as to the need for a suitable apparatus to measure the moisture content of sand, suggested that the difficulty could be overcome easily by installing a sensitive rotary water meter on the actual mixing equipment. In

some tests he had carried out recently, he had overcome the trouble entirely by installing a water meter, and it appeared to be more reliable as a means of moisture control than any existing instruments for the quick determination of moisture content. Over a period of about three months, with a mechanical sand-mixing equipment, and using a water meter, he had been able to control the moisture content to within 0.5 per cent.

Referring to Fig. 4a in the Paper, showing a specimen charge sheet for cupola work, Mr. Hudson pointed out that the amount of limestone added per charge was high, being over 90 lbs. per ton of metal. He asked if there were any special reason for the use of this quantity, as normally one expected to use about 50 or 60 lbs. of limestone per ton of metal.

He was also particularly interested to note the importance attached to the use of core washes for oil-sand work. Many foundrymen were of opinion that oil-sand cores did not need a core wash, and when rough castings were obtained they were only too ready to put the blame on to the core oil or binder used, or upon the sand. So far as oil-sand cores were concerned, it could be accepted as a definite rule that the factor affecting the surface finish of castings was definitely determined by the type of sand used. The more open and coarse the sand, the greater the need for a core wash. Conversely, the need for core washes was reduced by the use of a close sand, such as a red-sand admixture, but the cores became less foolproof and greater technique was required in their use. He asked Mr. O'Sullivan for a general indication of the core-wash mixtures used in his practice.

Core Washes.

Mr. O'Sullivan, dealing with the limestone charge, said the standard charge was 80 lbs. per 2,400-lb. charge of iron, but it varied a little at times.

With regard to cores and core washes, he said the cores used were not all oil-sand cores; there were several others. A great many of them were immersed completely into the wash—and if there were anything in a badly rammed core to be searched out, it could soon be done by immersing the core in the wash. Of course, in oil-sand cores much depended on the amount of oil used in the sand, and one could make oil-sand cores which would disintegrate very rapidly when the metal touched them. At the Cork foundry the minimum amount of oil considered possible was used in oil-sand cores. In a water-jacket core it worked out at 66/1 by volume, or nearly 100/1 by weight. Otherwise, as a general rule, they did not dip oil-sand cores. Sometimes they dipped a small section of a core, which might be a water-jacket core.

Mr. Hudson said that when he had referred to oil-sand cores he had not meant to imply that the cores should be strictly oil-sand; what he had really meant was a core with any artificial bond.

Mr. O'Sullivan added that they dipped cores because, when they were making a cylinder block, for instance, and the block was cast as a unit, the cores must strip freely and the casting must be smooth and clean. They also rumbled the castings, and the cores came away very easily then. The metal was poured as hot as it could be obtained from the furnace; the core stripped easily and there was no trouble when the casting was rumbled. That had been his experience.

An Object Lesson in Quantity Production.

Mr. J. A. Smeeton expressed his thanks for the Paper, which he described as the most modest he had ever read. He recalled that when he had visited Cork, about 2½ years ago, it was suggested to him that before he discussed the matter with which he was then concerned he should spend 24 hours in the foundry, and then discuss the matter in the light of the knowledge so gained. He had adopted that course, and one of the officials of the foundry had spent part

of two working days with him. His first difficulty, however, was to find the foundry at all; the cupolas were at one end of a huge building, and they seemed to be the only equipment of a normal foundry that he could discover. The remainder seemed to be an up-to-date machine shop. Reference had been made already to the keenness of the men employed there, and he doubted whether it would be possible, in any foundry other than that of the Ford Company at Cork—except, perhaps, at the Dagenham foundry later on—to produce castings at such a rate as that at which they appeared to be produced on the moulding machines at Cork. At one time they were producing per day 300 tons of castings, weighing anything from a few ounces to 2 cwts. or less, and he had marvelled that they were turned out in such an excellent manner. One could write a Paper on almost every phase of the foundry work. The mixing of the sands, the making of cores, the drying, the heating of the different moulds and every other detail seemed to have been worked out religiously, not on the text-book basis, but on the basis of some superior knowledge which seemed to have been gained by the Ford organisation, probably at the American works. The output achieved was almost unbelievable, and the fact that so many of our modern works were copying the general principles which undoubtedly had been introduced into Europe by the Ford organisation was proof that they were on the right lines. We were copying, and must continue to copy, many of the principles applied at the Ford works. Mr. O'Sullivan might well have written a book on the subject, rather than a four-page leaflet, which latter did not give a real impression of the organisation. There was no dirt in the foundry, no loose sand, and a visit to such a foundry was an education. He strongly advised every foundryman in this country, if the opportunity occurred, to visit the new Ford foundry at Dagenham, which he believed would be even greater and more up-to-date than the Cork foundry, and where they

would be able to see moulding and quantity production *de luxe*. No ordinary foundry could afford to instal such plant as that which would be used at Dagenham, but foundrymen would learn from it much that they could adapt and adopt in their own individual foundries.

Mr. A. Harley (Past-President) asked whether the Ford Company had made any tests to ascertain the difference in the wear of the low-phosphorus iron used at Cork and of the normal phosphoric iron in general use for cylinder production. He also asked what Mr. O'Sullivan considered to be a normal percentage of scrap in the foundry on cylinder work, and the normal percentage of scrap in the machine shops. When using the word "normal," he meant at what percentage did complaints begin to arise with regard to foundry operations.

Reducing the Scrap Pile.

Mr. O'Sullivan said the experience of the Ford Company was that for cylinder heads, or cylinder blocks, where there were uneven thicknesses of iron a lower phosphorus content was distinctly beneficial. They did not get leaky bolt holes in cylinder heads, for instance. On one head, the average thickness was $\frac{1}{8}$ in. or $\frac{5}{32}$ in., and there were heavy bolt holes and sparking-plug recesses close together; segregation occurred there if higher-phosphorus irons were used. With regard to wear, the Brinell figures specified were 180-200 for the bore. As to the percentage of scrap, he said that no doubt there would be complaints if it were as low as 0.05 per cent. After all, when criticism was stopped, progress was stopped; when one said that everything was fine, and could not be better, it was time one retired. Of course there was a limit, but things could never be too good, and there was always room for improvement. He had known the scrap on cylinder to be as low as 1 per cent. and as high as 20 per cent. When a particular job was put into production, the first day's scrap would probably be high, but on the second day it was down to normal—probably from 3 to 5 per cent.,

that figure including rejects from the machine shop. When a job was running well, the scrap could be reduced to 1 per cent. Last year, when in the United States, he had seen the making of clutch housings, and so on, and the scrap produced was 0.5 per cent. They were making about 8,000 parts a day—and, of course, if one were making only a few castings, the percentage would be higher.

Dealing with the question asked earlier by Mr. Gardom as to how production was maintained, he said that if they could run two shifts on an article they did so. Some little time ago the production of a particular item was commenced; they had started a new shift altogether on this particular item, and the production was about 60 moulds per hour. They happened to have a night shift at the time, and the men, when they came in, looked at the production board and said they would try to beat the previous figures. One night they had produced 100 per hour. That indicated the spirit of the men. The men must work fairly regularly, but the production was not so great in the first hour as in the second, third or fourth hour of a shift.

Mr. Faulkner asked if the rate of production dropped towards the end of the shift.

Mr. O'Sullivan replied that the first and last hours' production varied a little from that of the others. That applied to furnace work also.

Mr. Smeeton asked if the men worked as they did as the result of sheer keenness and rivalry, and were not paid piece rates.

Mr. O'Sullivan said there was no piece-work; every man was paid hourly.

Mr. Smeeton: Irrespective of what he does?

Mr. O'Sullivan said that that was so. They used air-jolting machines and air squeeze. A man engaged on making cope and drag would make 100 parts of a mould in an hour, sometimes as many as 120, and he had seen them make 132. The best production that had been attained was 910 in eight hours.

A Member said that that would vary with the depth of the box and the complication.

Mr. O'Sullivan agreed that it would vary with the size of the box. They used a standard flask for many jobs; they could put in two of some and ten of others, and they were approximately 21 in. between pin centres.

A Member said that the sand was fed from overhead bins, of course, and all that was necessary was to lift the box off the machine and place it on a runway.

Mr. O'Sullivan said there was no shovelling. The man put the flask on the machine, pulled the hopper gate and jolted. He placed it on a revolving stand. When he took the mould off the machine he could not place it at his side or in front, but had to turn round. That movement seemed superfluous, but it could not be eliminated.

Mr. A. Harley (Past-President) said that many foundry difficulties were overcome by the use of a low-phosphorus iron, but he asked if any trouble had been experienced in the valve seats, owing to the relatively softer nature of this metal.

Mr. O'Sullivan replied that he had not experienced trouble in the valve seats if the Brinell hardness were kept down to 200, or probably 210. They claimed that the range indicated was the best specification.

Salving by Welding.

Mr. W. Scott, commenting upon the remark made by Mr. O'Sullivan that the total carbon content specified was from 3.2 to 3.5 per cent., asked if he had had experience of the use of irons of low total carbon content. His own experience suggested that if the total carbon content were reduced to the vicinity of 3 per cent. it would not be necessary to work to within such fine limits with silicon and phosphorus as Mr. O'Sullivan had indicated; there would be greater latitude.

With regard to the influence of rates of pay upon production, his impression was that the standard rates paid by the Ford Company were better than the pay of piece-workers in many

other works, so that that provided an incentive. He also asked how such a plant could be made to pay when trade was bad and production was reduced to one-third.

The most candid statement he had ever seen in a Paper was the admission, in the last paragraph, that defective castings were repaired when possible. He asked if electric welding or fettling was adopted. He was glad that Mr. O'Sullivan had been candid enough to say that welding was used; everybody else seemed to hide it.

Mr. O'Sullivan said he saw no reason for hiding the obvious or for scrapping a casting for its looks. Some castings were gas-welded and put through a furnace, and some were electrically-welded. This work was regarded as a necessary evil, but, after all, much money was spent on castings, and further, welding is now a much better job than it used to be. One would hardly believe what could be done with welding at the present time. With regard to the total carbon content of the iron, he did not experience difficulty in working to the close limits indicated. At one time there had been some difficulty with the total carbon, but he believed that was due mainly to the working of the furnace. The influence of the total carbon content showed itself plainly when the castings were machined; if the total carbon content were too high, the finish of the surface would be very poor. The cupola was started at 7.40 or 7.45 a.m. in the morning, and when it started melting they did not alter the blast. If they wanted to run at full speed they put it on and kept it at that, and did not throw it off because the melting was too quick or too slow. Particular attention was paid to charging the furnace a regular number of times per hour, and they did not have trouble with total carbon content if it were within 3.2 to 3.5 per cent., and the castings had a good finish.

Mr. Scott said he had in mind Mr. O'Sullivan's earlier statement that there was some difficulty in securing sound metal around certain bolt holes if there were variation in the

content of silicon and other elements. His suggestion was that if the total carbon content were 3 per cent., the silicon content could vary within greater limits than had been indicated and the metal around the bolt holes would be sound.

Mr. O'Sullivan said they worked to rather a higher silicon and phosphorus content sometimes, but maintained the total carbon content within the range indicated. He appreciated Mr. Scott's suggestion, but it was found that when working within the lower ranges of silicon, phosphorus, and so on, there was a tendency for it to become difficult to keep the total carbon content so low.

Mr. Smeeton said he gathered that there was no attempt to bring down different metals from any one cupola, but that different qualities of metal were obtained from different cupolas.

Mr. O'Sullivan agreed. As a rule, he said, only one iron was run from any one cupola during the day, except that occasionally it was necessary to make a change at lunch time. That, of course, gave better control. If cylinder blocks were being made, iron for those cylinder blocks was melted in a particular cupola or cupolas. There was no splitting of charges.

Mr. J. N. Burns, of the Ford Motor Company, commenting on Mr. Gardom's expression of disappointment that the Paper did not contain more information about the organisation, said that the reason was that Cork was situated in a present backwater of the engineering world, and problems that were regarded as simple by the staff may present considerable difficulties to outsiders and *vice versa*. Mr. O'Sullivan had, therefore, presented a broad picture of the organisation, and relied upon members asking questions so that any particular detail could be amplified.

The whole system at Cork could be summed up in the word "facilities"—that was the secret of the whole organisation. In the foundry, if a moulder wanted a flask, it should be within easy reach; if he was required to take four steps, they should be four clear steps; and if an accu-

mulation of sand interfered with his movements, then his efficiency was reduced. It would be realised that there was no margin for unnecessary motion when a moulder was making 100 moulds per hour.

With regard to the costing system, the practice was to cost the castings on the "minute" system; the production of any casting occupied so many men so many minutes, and the resultant time cost was given as a "minute cost." The ultimate cost was then a matter of factory-accounting, and was naturally a function of the general efficiency of the plant.

Referring to the question of the policy adopted during the short-time periods, this is purely a matter of compromise. It was, of course, most efficient to shut down completely and reopen only when sufficient orders had accumulated to justify the various sections working at full capacity. However, customers' requirements must be considered, and so it was often found necessary to operate at reduced efficiency to meet immediate urgent demands.

The PRESIDENT, in view of the statement in the Paper that defective castings that could be salvaged were put through the reheating furnace, welded, and then either passed or finally scrapped, asked if the reheating or annealing or normalising of every casting would be advantageous. He asked because he understood that a certain firm who were making electrical plant first rough-machined castings for big alternators and then put them through an annealing furnace, where the casting stresses expended themselves; it was then found that the rough machinings were not anywhere near where they ought to be, and, therefore, they finished the machining after annealing.

MR. O'SULLIVAN said that at Cork they had annealed castings and had found that if any machining operations had been done on them they did not come within the specified limits when measured by gauges. Furthermore, they obtained very good results with very plain, simple castings when they gas-welded them.

CONTRACTION, DISTORTION AND CAMBER IN GREY IRON CASTINGS.

By E. Longden.

A limited amount of excellent work has been carried out on the phenomenon of distortion and irregular linear contraction in grey cast iron. But so far as the author can ascertain, such efforts have been concerned with test-bars and light castings. Turner, Mallet, Roberts-Austen, Keep, West, Hatfield, and in the more practical school Heggie, all deal with the subject either on a laboratory scale or within the limits of small and light castings.

A knowledge of what happens when a plain simple casting cools from the molten condition to normal temperature is up to a point helpful, but such information is too limited unless, at the same time, a thorough examination is made of the causes and influences which hinder and mask ordinary contraction in large and complicated castings.

Since it is obvious that solid contraction always operates in all types of castings, more interest will be felt with, and directed to, the standardising of the physical means for counteracting unequal and restricted contraction, and the attendant abnormalities, than with the underlying theories and their causes. At the same time more exhaustive and conclusive work is needed from the scientific side of the cast-iron industry.

There is a striking lack of data and standards for camber allowances in castings which need such treatment. This is expected, and again shows the illusiveness of iron casting production. The author has long sought for information which could be more or less readily applied, but after exhaustive search over many years has come to the conclusion that reliable and easily

applied rules and standards for camber to overcome deformation do not exist. Such information as is available is very contradictory and dangerous.

Case of Light Castings.

With small and light castings of a repetition nature the necessary bends, contours or camber can be ascertained by trial and error without serious loss, but with large castings such methods would be fatal. Considerable experience and knowledge is, therefore, required when dealing with large and complicated castings. The author has made an effort to provide the starting point for a workable basis for camber standards in medium and large castings of bedplate design, but he cannot claim them to be perfect, as so many variables in design may be introduced which will modify the standards outlined.

The practical examples illustrating camber in large machine-tool castings will further illuminate the camber chart, Fig. 1 (pp. 112 and 113). No single condition or combination of conditions can be absolutely successful unless linked with an understanding of the principles underlying the conflicting phenomena of dual contraction and expansion common to grey iron. Each condition may be controlled in certain cases quite satisfactorily when such a condition can be properly measured and recognised.

Standard allowances for contraction are quite frequently wrong. Rarely does the casting contract more than standard allowance. Castings with many complicated cores like headstocks, gear boxes and cylinders do not contract to standard rules due to the resistance of the cores to the contracting metal and the general compactness of design. Heavy castings similar to hammer-blocks, flywheels or ingot moulds do not contract in conformity with the ordinary standard allowances which can be attributed to the massive growth of graphite.

The same amount of metal poured into a simple plate, a gear box and a plain block casting will, therefore, disclose altogether a different

behaviour in the three castings. In the case of the plate, deformation is due to irregular cooling and contraction in spite of regularity and simplicity of design. On the other hand, the gear box will warp little, but it can be readily understood that strains and stresses will be present but not so obvious as with the plate. The simple block-casting will be truer to the mould outline and free from contraction warps.

The rack casting shown in Fig. 2 describes how easily one can misjudge distortion and

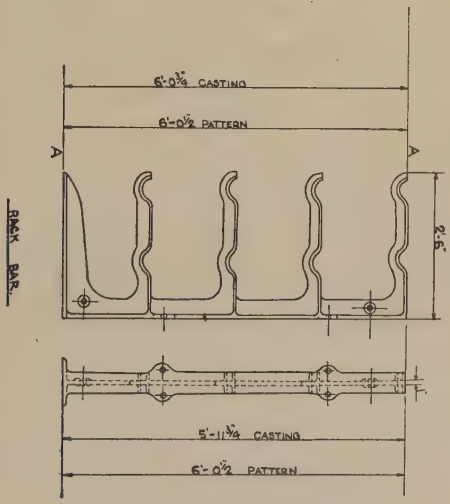


FIG. 2.—RACK BAR CASTING.

camber allowances. The distance between the points AA is $\frac{1}{4}$ in. wider in the casting than the pattern. The contraction in all other respects is regular. The tendency of a metal is to contract strongly in the direction of the longest section of material. Another factor which creates the irregularity is the resistance of the sand between the arms to contraction. L-shaped and U-shaped castings always show the same kind of irregular distortion.

Design.

Whilst design has a most important bearing on the deformation and ultimate strength of a casting, grey cast iron must be considered on the widest basis possible. Unfortunately, the average draughtsman or designer lacks sufficient knowledge of the changes which take place in metals, especially cast iron, when cooling from the fluid to normal temperatures. He invariably fashions the shape and dimensions of a casting based on the theoretical strength of cold metal, ignoring generally the contraction and expansion strains and stresses peculiar to cast iron. As a rule, if the designer is in doubt, more metal is lumped on a section for safety. Very often the thoughtless additions of metal locally aggravate and intensify the very weakness or trouble which it is intended to obviate.

The great tendency is to make those sections of a casting which carry the immediate duty of a machine or engine too heavy in relationship to the rest of the casting. If instead of playing for apparent safety by adding more metal to an important section such addition was distributed to bring the casting generally to more equal thicknesses, the structure would be more free from strains and stronger in these sections where strength is most needed.

Again, equal sections are not *always* desirable, as an outer wall of metal will cool more rapidly than an inner wall of equal section, thereby weakening the casting from the general strength point of view, apart from the careful consideration the foundry authorities must give to the securing of a casting without undue deformation or freedom from probable fracture.

Closer collaboration on such points between designing department and the foundry and pattern shop executive is very necessary. Such collaboration is considered as of the first importance by the author's company, with very beneficial results.

Composition and Deformation.

The volume changes peculiar to cooling cast iron increase the difficulty of studying contrac-

tion and distortion. Expansions and contractions are operating at one and the same time in all castings however simple. It may be that an expansion of one part of a casting may cancel out the distorting effect of another contracting section so far as deformation is concerned, although not without leaving stress and strains in the casting. Yet the same conditions operating in another section or different type of casting may mean much deformation, or actual fracture. This aspect of cast iron in relationship to its effects on deformation needs a little more light.

Under ordinary conditions a high phosphoric iron will produce castings with less deformation than iron low in those elements. This knowledge is taken advantage of in the production of light castings. But in medium and heavy castings such a metal will tend to produce weak or fractured castings.

A hematite iron of No. 3 composition will give the least distortion if sufficient super-heat be imparted to the metal during melting, so that every section of the mould cavity can be completely filled. The danger from such metal lies in its comparative short range of fluidity, especially when used for light castings.

The strength and usefulness of an iron of the hematite nature to resist fracture and used for castings such as ingot moulds can best be judged by its universal adoption for such purposes. It would appear that the composition, form and orientation of the crystal grains allows the grains greater freedom of movement when the general structure is subjected to a sudden rise in temperature. It is this elasticity which makes hematite irons highly suitable for ingot moulds, slag ladles and the like. It has often occurred to the author that the ideal ingot mould metal would be one in which practically all the carbon existed as graphite.

Ingot Moulds and Hematite.

Ingot moulds up to 50 tons with wall thickness of 12 in. or more are poured with a hematite

metal of approximately 2 per cent. silicon. With such sections 0.5 per cent. silicon would give a grey cast iron, but the mould would fracture when the first heat of steel is poured into it. A strong close-grained low-silicon iron would be unsuitable for light work, or medium castings of large superficial area. Such a metal distorts very considerably.

The effect of volume changes on distortion can be illustrated by a study of a large bedplate casting similar to Figs. 3 and 4. The sections vary from 1 to 4 in., with heavier sections locally. The thinner-sectioned walls will cool off much more quickly than inner walls of similar section. Then there is the extremely slow cooling of the heavy sections cast face down in the mould. The cooling rate of this mass of metal is further reduced by virtue of its location in the hottest part of the mould, which is due to the poor heat-conductivity of sand. This heavy section will be passing through its expansion changes at a period when the thinner sections are rapidly contracting, hence conflicting stresses and strains resulting, at the best, in distortion of the casting.

Volume Changes and Composition.

The phenomena of volume-changes have been exhaustively dealt with by the virile O. Smalley. But no better or more simple illustration could be presented than the work of the late Mr. Broughall, of which sufficient note has not been taken. Again, the author, without knowing of the previous work of Mr. Broughall, carried through a number of experiments in 1920, the results of which were disclosed in a Paper in the same year.

Mr. Broughall demonstrated that when metal of grey iron composition was poured into a metal mould to form sticks approximate 4 in. dia. for gear blanks, that not only is there no liquid shrinkage but that, on the contrary, an actual exudation of metal appeared on the top open end of the mould. This shows the enormous compressive action of precipitated carbon when thrown out of solution.

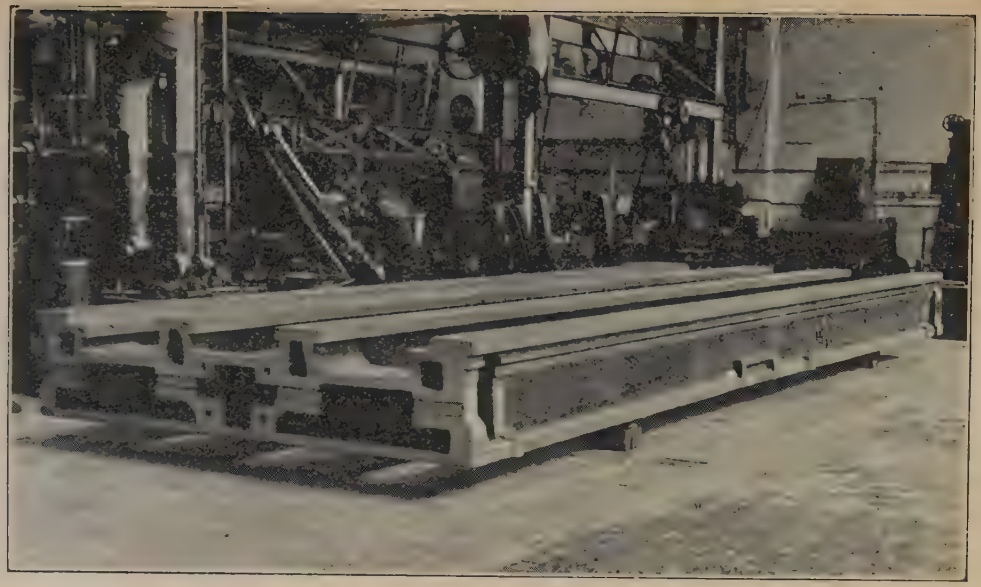


FIG. 3.—LATHE BED CASTING CARRYING METAL SECTIONS FROM 1 TO 4 IN. THICK.

The author's experiments were conducted with a view to finding out the influence of various kinds of mould materials on the resultant casting. The results proved that the strength, closeness of grain and general freedom from un-

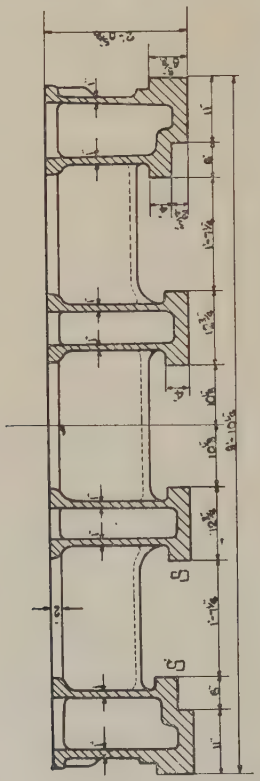


FIG. 4.—SECTIONAL ELEVATION OF THE LATHE BED CASTING ILLUSTRATED IN FIG. 3.

soundness improved in direct ratio to the strength and resistance of the particular mould material and general freedom of mould gases. The experiments cited, along with desultory tests taken over several years since, prove conclusively that, so long as the constituents of the

metal will produce a grey iron when cold, if the same metal be poured into a suitably strong mould without the use of feeder heads, that fluid shrinkage as is generally understood will be almost absent. The metal will be sounder than if a huge feeder head had been employed.

Experiments in Chilled Rolls.

During experiments in the production of chilled rolls, the author decided, due to the results of the previous experiments, to depart

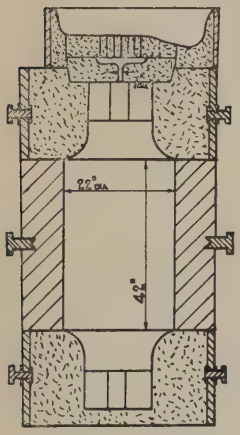


FIG. 5.—CHILL ROLL WEIGHING 2 TONS CAST WITH FILTER RUNNER-GATE.

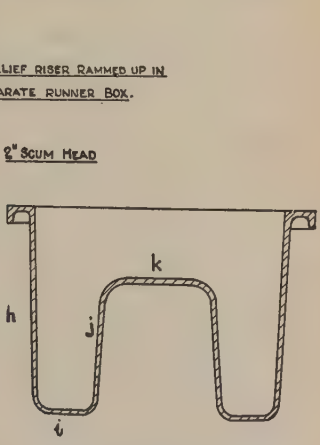


FIG. 7.—SECTION OF AN OIL-ENGINE BED WEIGHING 3 TONS.

from the orthodox rules and cast a 2-ton chilled roll through a top filter runner-gate, as indicated in Fig. 5. No attempt was made to feed this casting, which was subsequently broken up in the vital places and no liquid shrinkage was disclosed in any of the broken sections examined. The metal poured into the casting was of the following composition:—total carbon, 3.15; silicon, 0.65; manganese, 0.4; phosphorus, 0.35, and sulphur, 0.09 per cent.

The result was a little more convincing than was expected since such a metal is of the borderline type, and must yield approximately 1 in. of chilled white iron on the roll face. It is not uncommon to loose a chilled roll due to the bursting of the chilled shell which has contracted away from the expanding metal mould. Molten metal generally exudes through the fracture.

It is obvious that the bursting of the shell of a roll is primarily due to the enormous pressure of the progressive growth of graphite on the solidifying interior of the casting, although the static pressure of the still molten interior, along with the feeding process, is a contributory factor. An ordinary green sand mould allows the distending shell of the solidifying casting much more freedom than an extremely rigid cast-iron mould.

Mould Materials.

Mould materials have a strong influence on the density and soundness of grey cast iron. A metal mould produces the densest metal and a green sand mould the most porous metal. Mould materials can be placed in the following order, commencing with the material which has the greatest effect in improving the quality of the metal:—metal mould; ganister mould; dried-loam mould; dried-sand mould, and green-sand mould.

It is generally assumed that the specific gravity of cold grey iron is greater than that of molten iron. If this be so why does cold grey iron float on a bath of molten metal of grey iron composition? Is this not conclusive evidence that cold grey iron is of lower specific gravity than molten metal of a similar volume and composition? Hammer blocks will sometimes fracture on the extended surface which forms the base of the casting. This again would appear to be caused by the bursting action of the distending sides of the heavier section.

During his apprenticeship the author was often puzzled over the breakage of a large square loam-moulding plate $4\frac{1}{4}$ in. thick and 40 tons

in weight, which completely fractured across from side to side. This again suggests carbon changes as the cause of the breakage. The central and hottest zone of the casting would be expanding whilst the outer fringe was contracting and in tension. The central portion would have a considerably greater percentage of graphite than the outer zones.

It is generally known that large castings after machining distort somewhat. This is considered to be brought about by a reduction in the comparative strength of the machined area against that of the unmachined area. But the author considers that this explanation is not quite adequate. It would be reasonable to consider that the cause of the distortion was due to the pent-up stress in the casting.

A striking example of the locked-up stresses can be illustrated by reference to Fig. 6, which is a sketch of a flywheel 33 tons in weight, cast in four-quarter sections. After machining the contact faces, the four sections are secured together by special joggles as indicated. Consternation reigned when, after the roughing cut had been taken over the rim, small cracks were discovered radiating from the sharp angle X in the joggle seating. As is usual in such cases, the foundry was immediately saddled with the responsibility for the defect, although no change of any description had taken place either in the metal or in the method of manufacturing the casting. The matter was hurriedly reported to the managing director, who was also the designer of the flywheel. He immediately stated the cause of the trouble, which had been experienced before—many years previously. It transpired that the correct practice had been for the fitter to locate the steel joggles so that the flat side of the steel fastening sat only loosely on the cast-iron flat machined face X of the joggle cavity. Due to incorrect machining the joggles were a very tight fit, and had been heavily driven into position with a sledge hammer. After the rough cut the tendency of each quarter to straighten out created a tremendous pull on

the steel joggles, resulting in the small fractures indicated. The joints C opened $\frac{3}{64}$ of an

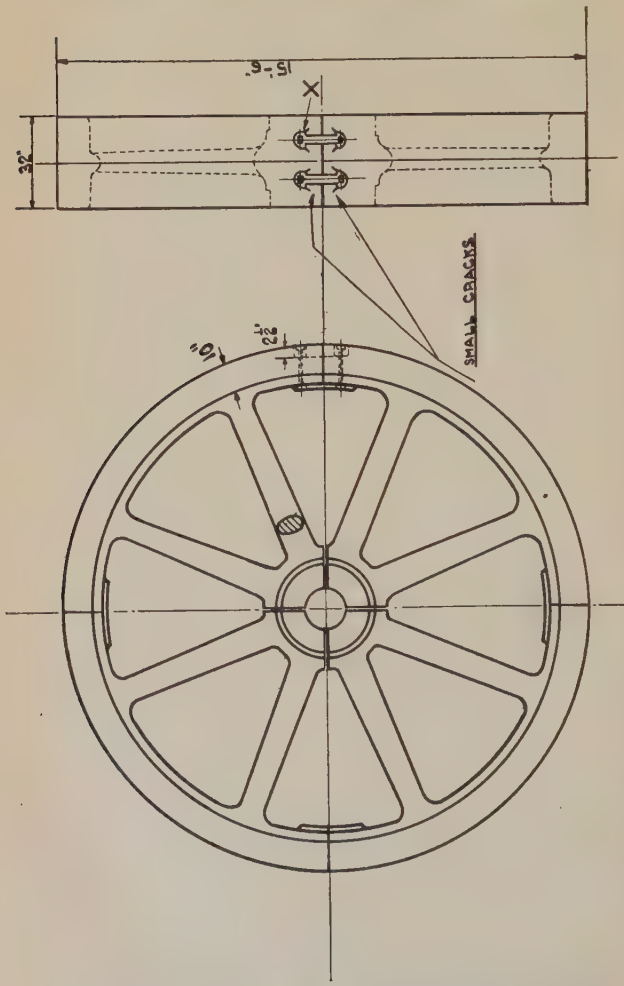


FIG. 6.—FLYWHEEL WEIGHING 33 TONS CAST IN QUARTER-SECTIONS.

inch. Fortunately the cracks were only slight and the flywheel was saved by machining out

the joggle holes until the cracks disappeared and special larger joggles substituted for the smaller ones.

The several examples shown of representative heavy machine tool castings illustrate further the subject. The 26½ ton section bedplate shown in Fig. 3, after rough machining, will camber to the extent of becoming concave $\frac{5}{64}$ in. in the centre. This inclination to deform is in the same direction as when cooling after pouring.

It is necessary during the machining of the bedplates first to rough-cut the top surface with the casting lying on the machine-table without bolting down. During subsequent and final machining operations, the holding-down bolts are released—perhaps twice to accommodate any further slight camber. The need for care and experience is made clear when it is found necessary, say, with a bedplate 30 ft. long, to machine to an accuracy on the top shears to within a maximum error of 4 thousandths, and sideways the same bed must be true and dead straight to within a minimum error of 2 thousandths, and must be entirely free from cross-wind.

Temperature of Metal.

Wide variation in the composition of the metal will not influence contraction in light castings to anything like the same degree as a wide variation in temperature. This applies more particularly to plated castings with thicknesses ranging from $\frac{1}{8}$ to $\frac{1}{2}$ in. With more massive castings, temperature differences are not too marked so far as distortion is concerned.

A simple plate $\frac{1}{4}$ in. thick and 2 ft. square, cast in a 2½ per cent. silicon and 1¼ per cent. phosphorus iron, and poured at a reasonably high temperature—1,350 deg. C.—will warp so that the centre is $\frac{3}{32}$ in. convex as cast. Pour the same plate at a 100 deg. C. lower temperature and the deformation will nearly double. A similar plate cast in hematite iron of 2½ per cent. silicon will warp approximately $\frac{1}{8}$ in. at 1,350 deg. C., but if the temperature of pouring be raised 50 deg. the deformation is halved.

A similar plate poured in a low silicon iron at a temperature of 1,350 deg. C. warped $\frac{5}{32}$ in. and at 75 deg. lower temperature $\frac{7}{32}$ in.

It is not universally accepted that a test-bar, poured at a high temperature, is of better physical properties than one poured at a moderate temperature. But there is no doubt in the minds of those who handle cast iron on a large scale that castings poured at the higher temperatures are stronger and deform less than when poured at a lower temperature. Therefore the influence of temperature and fluidity has a marked effect on the tendency of light castings to deform and fracture.

The sudden solidification of a lifeless iron gives little time for the mould to reach an accommodating condition and temperature and steady up contraction stresses by equalising cooling. Oxide films and gases are rolled along before the metal and congest certain areas, preventing proper amalgamation of converging streams of metal and also the complete filling of the mould.

Fig. 7 describes the section of an oil-engine bedplate, weighing approximately 3 tons. It was decided to test the strength of various parts of the casting, and test-pieces were cut out of the casting at the places marked *h*, *i*, *j*, *k*. The following results were obtained:—

Separately-cast test-bar from the same ladle of metal as the bedplate casting yielded 11 tons per sq. in. tensile.

At point	*h*	approximately ..	$8\frac{1}{2}$	,,	,,
,,	*i*	,, ..	$7\frac{3}{4}$	,,	,,
,,	*j*	,, ..	$6\frac{1}{4}$	,,	,,
,,	*k*	,, ..	$4\frac{3}{4}$	,,	,,

These results emphasise the importance of the cooling rate; correct distribution of metal and the formation of that portion of the mould forming the dome over which two or more streams of metal converge and its venting. Any turbulence of the metal on the dome will reduce the strength of the metal, which has already become oxidised, and its temperature lowered in its passage upwards through the mould.

Influence of the Temperature and Composition of Mould Material.

Green-sand moulds have a greater tendency to produce irregular castings than dry moulds. Local and general swelling of a green-sand mould will upset the calculations for camber. On the other hand, certain types of castings which are made with green-sand cores are produced with less danger of fracture than if made with dry-

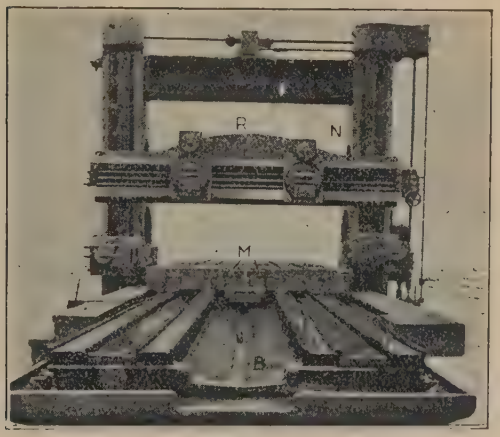


FIG. 8.—A LARGE PLANING MACHINE, THE WEIGHT OF WHICH IS ILLUSTRATED BY THE FACT THAT M WEIGHS 34 TONS.

sand cores. Therefore a dried mould will produce castings more in line with calculations and a hot mould will produce even better results. Cores irregularly placed in a mould will cause misshapen castings, hard resistant cores, or cores with iron reinforcements too close to the surface will interfere with the contraction of the casting; the influence of mould material has also been dealt with earlier in the Paper.

Influence of Methods of Moulding.

The shape, size and location of runner and riser, gates and feeder heads have considerable

influence on the final shape and soundness of a casting. It is good practice with bedplates and

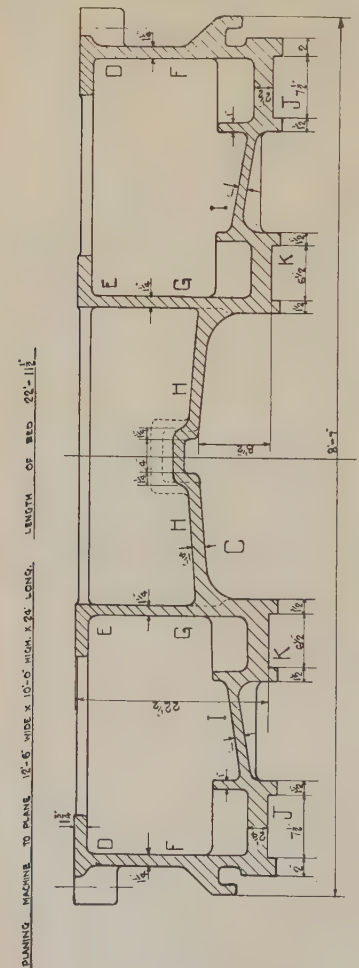


FIG. 9 IS A CROSS-SECTIONAL VIEW OF CASTING B IN FIG. 8.

castings of large area to free the sand around the runner- and riser-gate metal soon after the

mould has been poured and the iron solidified, and, also, to release binding-down tackle and bolts which have been used for securing cores.

With simple dish-shaped castings, the top sides of which are formed by directly ramming

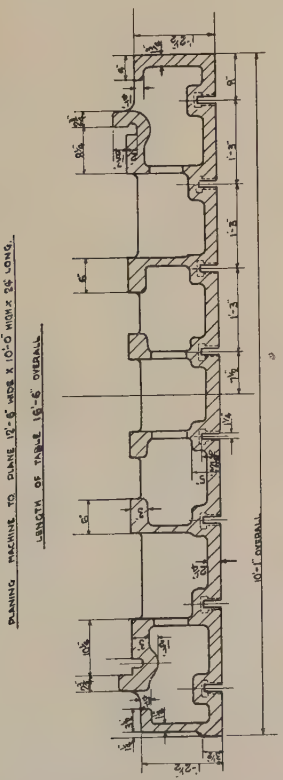


Fig. 10.—Sectional Elevation of the Table Casting M, Fig. 8.

sand into the interior of the pattern, instead of by cores, the distortion can be considerably reduced by loosening the gaggers or lifting-irons soon after the metal has set. Very often distortion or fracture can occur by ignoring the simple law of gravity. A casting contracts in all

directions, and may become suspended in the mould, due to the strong hold of the riser, runner gates and feeder heads by the surrounding material in the upper part of the mould.

Some time ago a certain company had a number of Diesel cylinder heads returned as

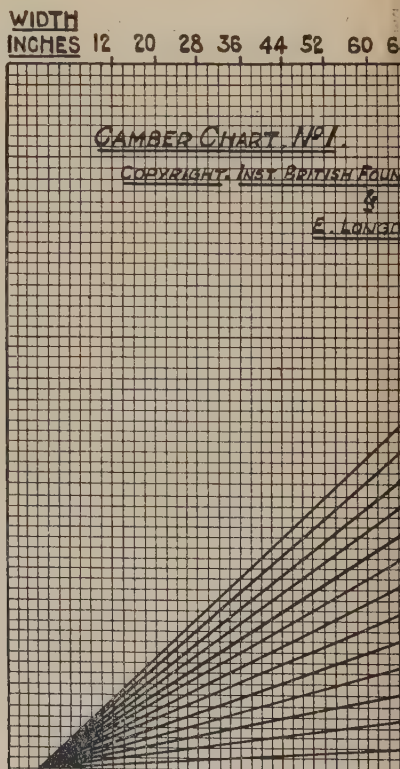
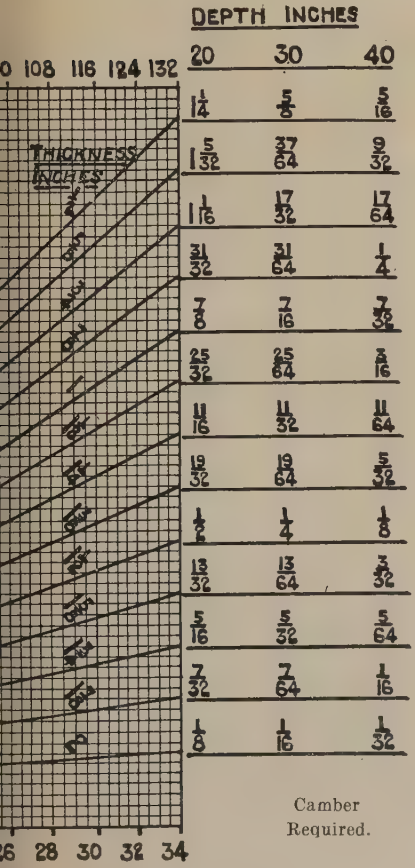


FIG. 1.—CAMBER CHART

defectives after machining. It was then discovered that a heavy feeder head had been placed on the centre of the casting. This massive feeder head, which remained fluid longer than the rest of the casting, was solidly held between two bars of the top part, and the cast-



IER TYPE OF CASTINGS.

ing below contracted causing a hot tear underneath the header which was not disclosed until the casting had been machined.

Camber and Distortion in Heavy Machine Tool Castings.

The following description of deformation and camber in large machine tool castings can be

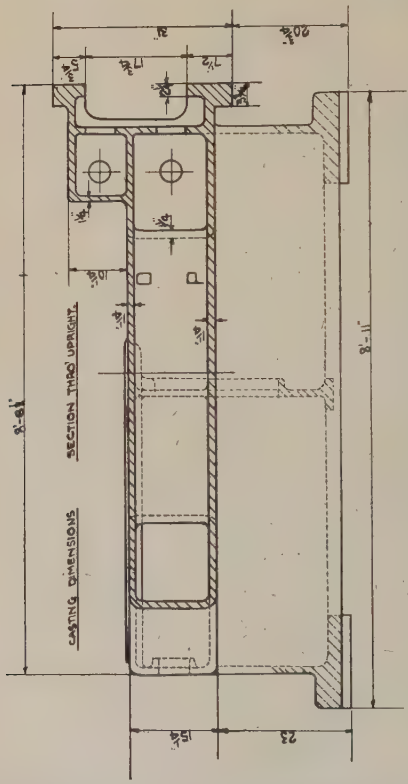


FIG. 11.—SECTION THROUGH THE UPRIGHTS (CASTING N), FIG. 8 WEIGHING 11 TONS.

taken as illustrative of heavy castings generally. Fig. 8 shows a series of castings constituting a large planing machine. The bedplate B, 60 ft. in length, is made in three sections, the heaviest

FIG. 12

of which is a 20-ton black-casting. Fig. 9 is a cross-sectional view of the casting shown as moulded with the machined shear-faces down. The metal is admitted at the lowest face to the mould at both ends.

In spite of the reasonable uniformity of section, $\frac{5}{8}$ in. of downward camber in the centre is needed to counteract the deformation due to unequal contraction. There is a continuous plate-section as shown in the sketch. It will be noted that the oil-sump C is $1\frac{1}{4}$ in. thickness.

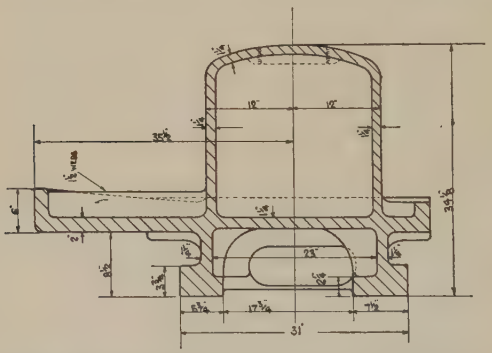


Fig. 13 shows Cross-Slide Casting R of Fig. 8. It weighs 6 tons.

If this section were only 1 in., it would probably result in a fracture across the face named at right angles to the sketch. The breakage would very likely occur from the following:— The casting would cool in the following order as indicated by the letters on the sketch, Fig. 9, D, E, F, G, H, I, J, K. The heavy sections J and K would at certain stages during cooling be expanding whilst other sections were contracting. The conflict would be most exacting on section I. The stress thus set up would be a probable fracture on final cooling down, as indicated.

Fig. 10 is a sectional view of the table M, Fig. 8, and 35 ft. in length; made up of two

parts; each 16 ft. 6 in. long, and 17 tons in weight. Although of a shallow and well-braced design, $\frac{1}{2}$ in. downward camber in the centre is needed to produce a straight casting in the half-table. The tee-head slots are partly cored out. The castings are poured through bottom in-gates, situated between the slot-cores at each end of the mould.

Fig. 11 illustrates the construction of the uprights in Fig. 8. The casting weighs 11 tons. Here it might be thought there is no need for camber. But if section O, Fig. 11, is increased by $\frac{1}{8}$ in. over that of P, then distortion would occur and camber be needed. Such an irregularity of section might be the outcome of the incorrect setting of the main body cores, or to slight floatation of the core, due to loosely-secured chaplets located to hold down the core. The upright casting is moulded with the face, marked Q in Fig. 12, uppermost in the mould. Metal is admitted to the mould through in-gates at the base of the foot and on the flat face P, Fig. 11. The cross-slide, R, in Fig. 8 is shown in cross-section at Fig. 13. The casting is 6 tons in weight.

The design is one of strength needed for such an important member of a large planing-machine. The rigid strength so necessary for the duty of the machine is in this casting reflected in the remarkably low casting-distortion on cooling. Although over 19 ft. in length only $\frac{3}{16}$ in. of downward-camber in the centre is needed. The casting is moulded slide-surface down, along which surface the metal is poured from each end of the mould.

A Large Lathe Casting.

Fig. 14 illustrates a 50-in. centre lathe—a typical heavy machine tool. The bed is 80 ft. in length and approximately 70 tons total weight made up of three castings, the longest section being 30 ft. and 26½ tons in weight, and illustrated in Fig. 3. Fig. 4 discloses the strong girder-like construction of the bedplate, which

suggests little need for camber allowance. But the design in this case is not too helpful to the foundry. The metal in the shears, S, cools very slowly, due to mass and location in the mould, with the consequent excessive growth of graphite. The precipitation of graphite and slow cooling of the heavy section indicated causes it to expand

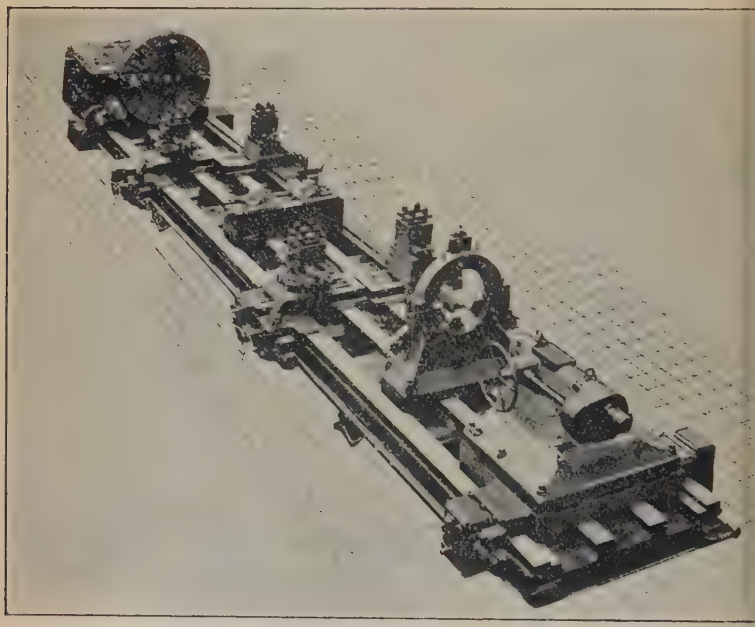


Fig. 14.

at a period when the general and thinner sections are contracting, which results in distortion. The 30-ft. bedplate mould is set down in the centre, *id est*—cambered—$\frac{7}{8}$ in., which produces a straight casting when cold. The mould is poured through each of the four shears from both ends.

A Bed-Plate and other Large Castings.

Fig. 15 shows a 13-ton bedplate casting for a 7-ft. railway wheel turning lathe, and Fig. 16 a sectional sketch of the casting. In design the casting will be strong, but the massive metal around the tee slots creates, again, a similar set of conditions, as previously outlined for the bedplate of the 12 ft. 6 in. planer-machine, except that the bearings on the plated section tend to retard their cooling, thereby approaching a little more nearly the cooling rate of the

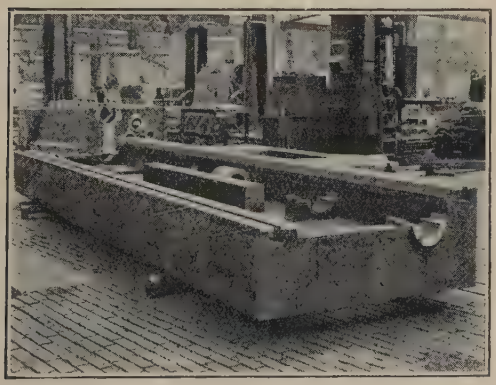


FIG. 15 SHOWS A BED-PLATE CASTING FOR A 7-FT. RAILWAY WHEEL-TURNING LATHE.

massive metal around the tee slots. Half-inch downward camber in the centre is allowed on this 21 ft. casting. The mould is poured from each end, through in-gates situated on both sides of the tee-head slot cores.

Fig. 17 shows a bedplate casting for a 26 in. centre-lathe weighing 13½ tons. It will be noted that, excluding the extra width of the head-stock end, the casting is only 4 ft. 6 in. in width, although 30 ft. 6 in. in length. The narrow section of the bed compared with the depth, along with the plated sections U, reduces

the general deformation and need for camber. An allowance of only $\frac{5}{8}$ downward setting in the centre is needed. The metal is admitted to the mould from both ends through the shear section.

Fig. 18 illustrates an axle re-turning and burnishing lathe. The bedplate casting is approximately 14 ft. long and 7 tons in weight. The general section is shown in the two sketches of Fig. 19. The camber in this case is the reverse of the previous examples described, and, instead of the centre, the ends are set down, although only $\frac{1}{8}$ in. This reversal of the camber is the outcome of the breaking up of the con-

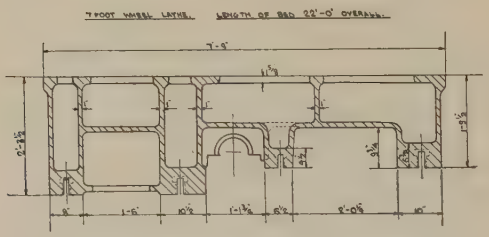


FIG. 16.—SECTION THROUGH THE CASTING SHOWN IN FIG. 15.

tinuity of the heavy shears by the gaps in the bed casting and, also, the comparatively greater depth and narrowness of the design. The casting is poured again from each end of the mould through the shears, but auxiliary gates are arranged to pass through the sand, forming the gaps between the shears. Figs. 20 and 21 show the $3\frac{1}{2}$-ton bedplate casting for a tyre borer. Contraction across the diameter at points V is less than standard, being only $\frac{5}{8}$ in., but across the casting at right angles to points V, the contraction is only $\frac{1}{2}$ in. Thus the casting is slightly eliptical, which can be ascribed to the contraction and pull of the trough-section, which is shown in the left hand of Fig. 21. The right hand sketch shows a fuller cross-sectional view of the casting.

The low contraction and slight deformation is the outcome of the resistance of a compact body of cores and the introduction of special denseners on the heavy section cast in the bottom of the mould. The mould is filled with metal through specially arranged in-gate cores, which run under the denseners to the centre of the mould. Further auxiliary runner-gates are arranged about midway up the side of the mould.

Fig. 22 shows a grinding machine with a narrow deep bedplate 28 ft. in length and

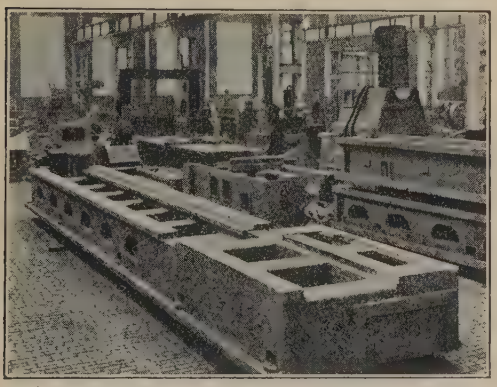


FIG. 17 SHOWS A BED-PLATE CASTING FOR A 26-IN. CENTRE LATHE WEIGHING 13½ TONS.

weighing 8 tons. In this case only a ¼ in. of downward camber in the centre is necessary. The casting is moulded the working face down in the mould. The metal is admitted to the mould in the V-sections at each end.

Generalisations on Camber.

Sufficient examples have now been given to provide the following general rules:—

Camber allowance, other dimensions remaining constant, increases with an increase in length of a casting.

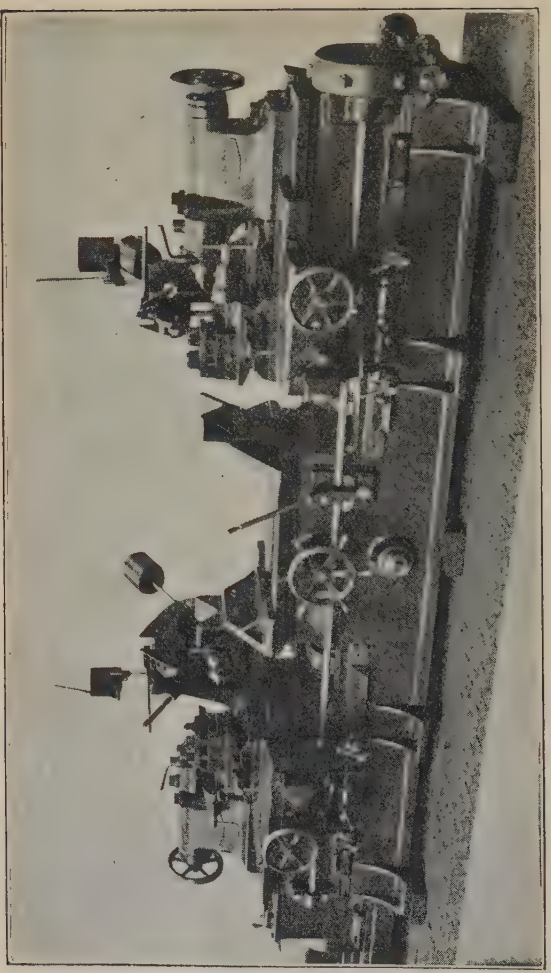


FIG. 18 SHOWS AN AXLE-RE-TURNING AND BURNISHING LATHE.

Camber allowance increases with a reduction in metal section.

Camber allowance must be decreased as the depth of the casting increases, without any corresponding increase in length.

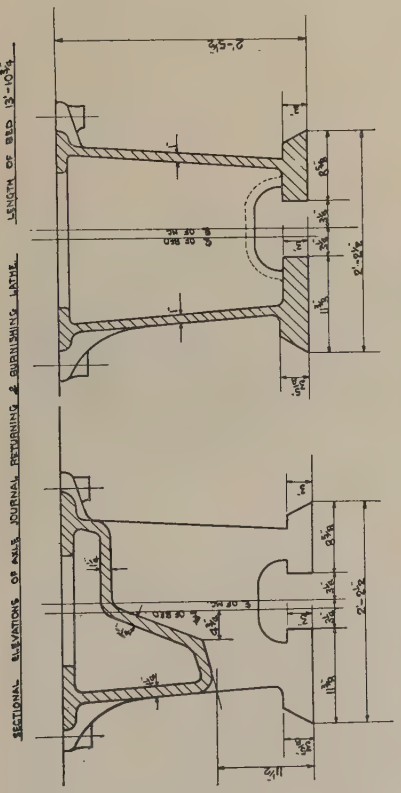

SECTIONAL ELEVATIONS OF 2½ JOURNAL PLANING & SURFACING LATHE
LENGTH OF BED 13'-10¾"
CASTING DIMENSIONS
SECTION THRO' VEE
SECTION THRO' GAPS IN BED.

FIG. 19.—SECTIONS THROUGH THE BED-PLATE CASTING OF FIG. 18.

Camber allowance slightly decreases with a reduction in width.

Camber allowance would have to be increased slightly with an increase in the plated area in the bottom of the mould.

Camber allowance decreases with an increase in the thickness of the metal in the bottom of the mould.

Camber decreases with an increase in the plated area in the top side of the mould, as against a casting made in the same way with a lesser plated area.

If, in the various examples shown, the castings had been box-shaped, that is plated sides and bottom and open at the top, and all sections equal—say 1 in.—quite double the camber outlined would be needed. Actually it would be

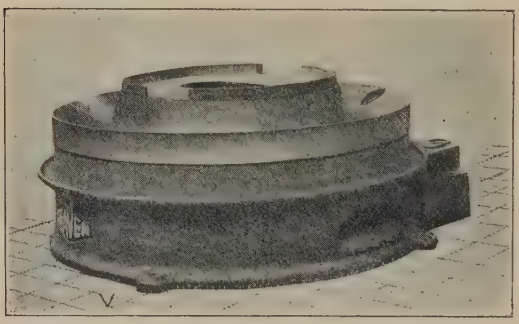


FIG. 20 SHOWS A TYRE-BORER CASTING.

almost impossible to produce a casting without fracture of an area similar to the bedplate shown in Fig. 3 and of 1-in. plated section throughout.

The camber chart, Fig. 1, and the foregoing will indicate the basis of camber allowances in medium and large castings, although care must be exercised in deciding on the camber since other variables in design may modify the rules. In the castings outlined temperature and quality of metal variation will not influence camber to any great degree.

It is important that no mistake be made by the moulders when setting the camber strips for

the bed of the mould. Errors may occur due to crosswinding and excess camber consequent on the sagging of the string which is used to set the camber strips. Greater accuracy is

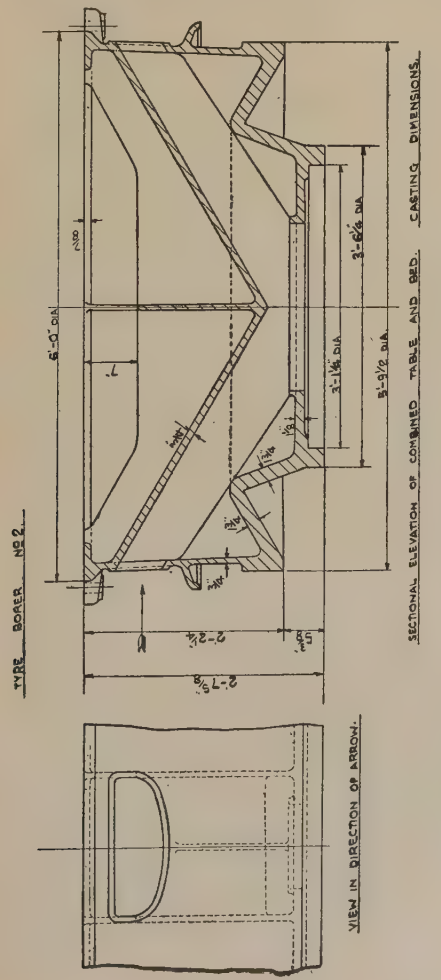


FIG. 21.—SECTION THROUGH THE CASTING ILLUSTRATED IN FIG. 20.

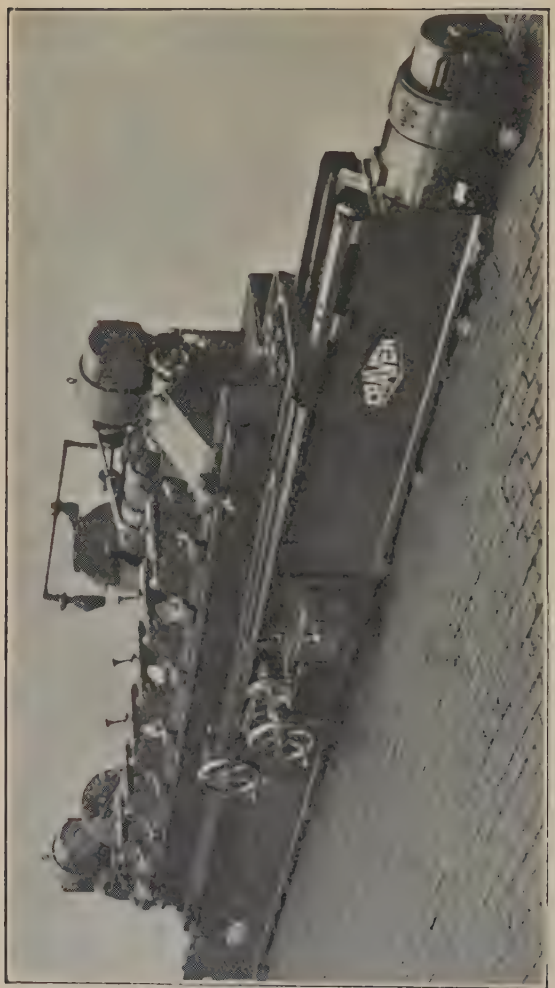


FIG. 22 SHOWS A GRINDING MACHINE WITH A 28-FT. BED-PLATE WEIGHING 8 TONS.

obtained when using wire for the latter purpose. It is important that all camber instructions be checked finally by a charge hand or foreman.

Shrinkage or Contraction Tests in Grey Iron.

The following notes may help a little to understand the cooling changes in grey cast iron and their effects on deformation, and can be considered as supplementary to the work of Heggie in 1914 and the more recent study by Servais in his French Exchange Paper of 1928. Mr. Servais' study originated from a difference of opinion between Mr. Goujon, the French metal-

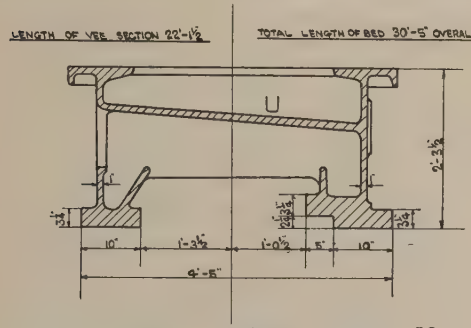


Fig. 23.—Sectional Elevation of a 26-in. Centre Lathe Bed Casting.

lurgist, and Mr. Ronceray. In a book written by Mr. Goujon on the subject of shrinkage, the author seemed seriously concerned with the anomalies which he discovered in special test-castings carrying thin and thick sectioned bars, shown in at *c*, Fig. 24. His conclusions were that, contrary to accepted opinion, thin sections have less shrinkage than thicker sections.

Servais asserts that Goujon ascribed the anomalies to the assumed fact that the rate of cooling of the thin parts is in inverse ratio to the thickness: the whole or part of their shrinkage takes place while the larger thicknesses are still liquid, and are capable of feeding the thin parts with sufficient metal to maintain

equality in length throughout the system. Ronceray in disagreeing with Goujon states:—

"I do not think that Goujon is correct; the

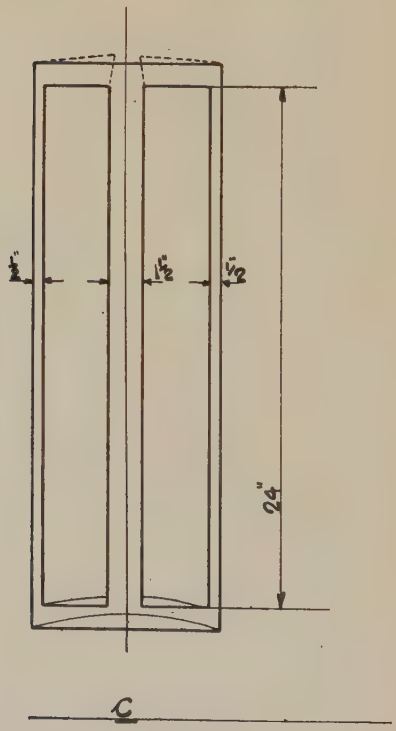
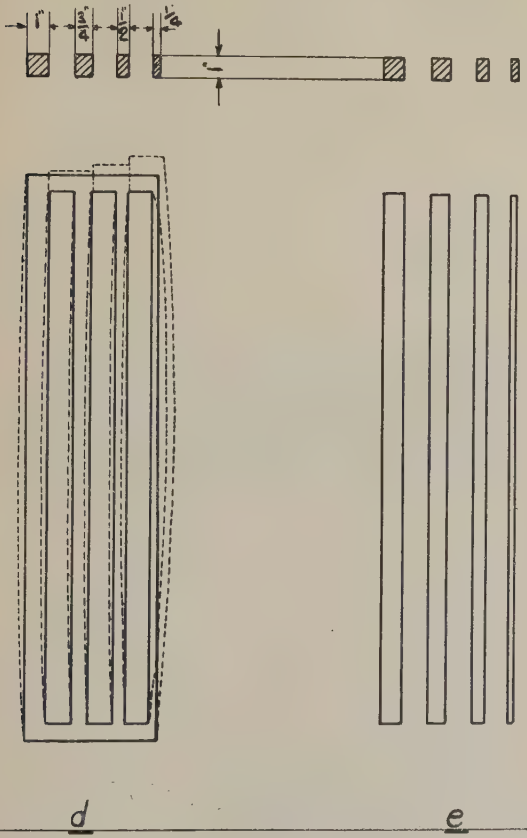



FIG. 24.—CAMBER EXPERIMENTS ON

shrinkage in length, in fact, does not begin to operate until after solidification, and it is, therefore, impossible to conceive of the thin parts being fed by the thick parts during

shrinkage in the solid state. At the most, the liquid shrinkage might be compensated. We must, therefore, look elsewhere, and the most



Various-Sized Bars.

reasonable hypothesis appears to me the following:—

The metal when heated must possess—contrary to what occurs when it is cold—a certain

property of elongation or of contraction; the solidified thin-parts are the first to exercise a tensile stress on the ends of the frames. As soon as they have become sufficiently solid, the ends are firm, and they act through the frame on the thick parts, causing them to shrink; the latter, being still pasty, yield to this stress, whilst at the same time the thin parts cool and become firm, the shrinkage of the thick parts then takes place, but it is opposed by the thin parts already cooled. The shrinkage thus creates internal tensions and cause fractures."

Servais encountered similar anomalies, as did Goujon, and after careful tests came to the conclusion that the explanations given by Ronceray were correct, and that thin sections

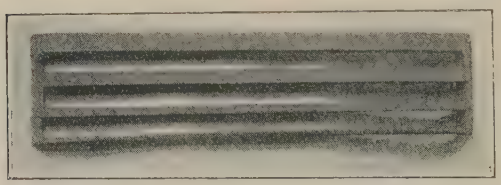


FIG. 25.—MULTIPLE BAR CASTING.

did contract to a greater extent than thick sections, as is generally understood. The present author cannot understand why simple comparative check tests were not taken in parallel at the same time. Similar sections of metal cast separately should have been tested at the same time.

The following experiments, whilst having no claim to be ultra-scientific, are simple and confirm the conclusions of Ronceray and Servais. Sketch *d* and *e*, Fig. 24, describes the test castings used in the experiments. Test-casting *d*, it will be noted, carries a series of bars $\frac{1}{4}$ in. × 1 in. up to 1 in. square, strung together by end sections, thus forming a grid-like frame. Similar sections of metal, shown at *e*, were cast separately. Test-castings were poured in green-sand moulds from the same metal, the analysis

being:—T.C., 3.3; Si, 2.0; Mn, 0.65; P, 0.85, and S, 0.12 per cent. The casting-temperature was approximately 1,350 deg. C.

The separately-cast bars contracted as follows:—1 in. sq.—$\frac{15}{64}$ in.; 1 in. × $\frac{3}{4}$ in.—$\frac{1}{4}$ in.; 1 in. × $\frac{1}{2}$ in.—$\frac{1}{4}$ in. full, and 1 in. × $\frac{1}{4}$ in.—$\frac{17}{64}$ in.

The multiple bar casting is shown in Fig. 25. A tap with a hammer easily fractured the sections connecting up the bars. The comparative lengths may be distinguished in the illustration. The $\frac{1}{4}$ in. bar is $\frac{3}{64}$ in. longer than the $\frac{1}{2}$ in. bar. The $\frac{1}{2}$ in. bar is $\frac{1}{32}$ in. longer than the $\frac{3}{4}$ in. bar

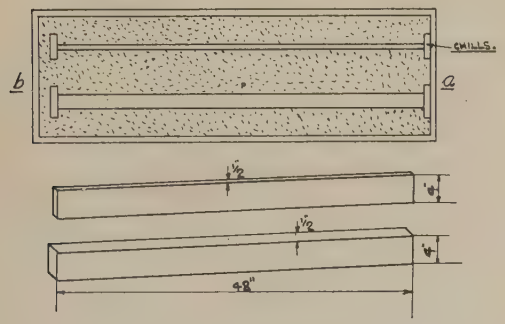


Fig. 26.—Further Test Examples.

and the last $\frac{1}{200}$ in. longer than the in. square section.

Before fracture, the casting showed the thin section to be cambered, as described in the sketch *f*, Fig. 24, and the thicker bars slightly the reverse way. After fracture, the thin $\frac{1}{4}$ in. bar cambered the opposite way a little and lengthened. The thicker bars retained most of the original slight camber, so far as could be reasonably measured.

The length of the thin bar compared in length with the same-sectioned bar cast-separately; but the thicker bars showed a slight reduction

in length compared with the thicker bars cast-separately and accounted for, mainly by the slight camber in the multiple cast bars. Whilst there was no evidence of elongation in the $\frac{1}{4}$ in. bar, the thick bars had clearly been compressed, probably during the pasty stage, causing a slight reduction in length by cambering the neighbouring thick bar on the adjacent side.

The sketches of Fig. 26 describe a further simple test. Two bars, $\frac{1}{2}$ in. × 4 in. × 4 ft. and 2 in. × 4 in. × 4 ft. were poured side by side from the same ladle of metal, the analysis being:—T.C., 3.25; C.C., 0.65; Si, 1.7; Mn, 0.6; P, 0.9, and S, 0.11 per cent. The ends of the bars were cast against machined chills. At one end "*a*" the chills were tightly butted against the moulding box side. At the other end "*b*" the chills were supported by solidly-rammed sand. The mould was made open green sand on edge and top-poured in the centre from a common pouring-bush. Table I details their behaviour.

Only one expansion, of course, could be noted, but it was very obvious when the chills at the end "*b*" supported by sand only were seen to be thrust back for approximately $\frac{3}{64}$ths of an inch. The movement appeared to last for about 15 secs. with the thin bar and with the thick bar 20 secs. This movement was confirmed the following day on examining the cold casting. The gap between the ends of the bars and the chills at "*a*" were a $\frac{1}{4}$ in. with both bars, and at the end "*b*," which had been constructed to allow and to respond to any post-solidification expansion, the gaps were in the case of the thin bar $\frac{19}{64}$ in. and the thick bar in.

It is quite evident that at a period, some time after solidification, that the casting is slightly larger than the mould. If the material composing a mould is strong enough to resist expansion and distension of the skin of the casting on cooling, or if the cooling of the outer envelope of the metal is accelerated so that a resisting wall of solidified metal is formed, then the energy released by the dissociation of carbon is returned

TABLE I.—*Expansion and Contraction of Experimental Bars.*

	$\frac{1}{2}$ in. by 4 in. by 4 ft.	2 in. by 4 in. by 4 ft.
Contraction after 15 minutes	$\frac{1}{8}$ inch	Nil
,, ,, 25 ,, ...	$\frac{9}{32}$,,	$\frac{1}{32}$ inch
,, ,, 35 ,, ...	$\frac{13}{32}$,,	$\frac{5}{64}$,,
,, ,, 45 ,, ...	$\frac{7}{16}$,,	$\frac{3}{16}$,,
,, at normal temperature	$\frac{33}{64}$,,	$\frac{31}{64}$,,
Expansion after 10 minutes	$\frac{1}{32}$,,	Nil
,, ,, 20 ,, ...	Nil	$\frac{3}{64}$,,

as a force to compress the inner and progressively solidifying metal layers.

Special mould conditions can therefore be arranged which will reduce fluid shrinkage in grey cast iron to vanishing point and at the same time produce a very dense structure in the metal generally. It will be seen that the contraction strains and stresses of grey cast iron are dual and very conflicting. Any considerations for camber allowances must take into account not only ordinary contraction, as commonly understood, but also the phenomena of post-solidification expansion peculiar to cast iron.

In conclusion, the author wishes to acknowledge his thanks and indebtedness to Mr. R. Greenwood, managing director of Messrs. Craven Brothers, Limited, Manchester, for help in the preparation of drawings, photographs, and facilities to carry out the experiments and permission to publish the camber data.

DISCUSSION.

Mr. A. Sutcliffe said he welcomed the Paper as being the most practical that had been submitted to the Institute for many years. He could not recall any other Paper which had mentioned camber since that which was read by Mr. H. Jowett before the Burnley Section in 1924 or 1925.* With regard to the bed mentioned in the Paper, the camber allowed was just what he would have allowed. The difficulty was that orders for lathe beds usually comprised only one of two castings to a given length, so that one had to decide upon the allowance to be made for almost every individual casting. He asked if Mr. Longden put the camber strips in the bed of the floor, or had he a full pattern with the camber in it; in most of the foundries in which he had made this class of work, he had only a short length of a pattern and sometimes it required shifting three times to make a casting 30 ft. long, such as planing-machine tables, side planers and lathe beds different in width or length. When

* "Proceedings, Institute of British Foundrymen," Vol. XVIII, p. 725.

making these castings the camber was mostly always obtained from the straight edges in the bed of the foundry floor. He suggested that the designer did not give enough allowance for machining these kinds of casting and that they had no idea of camber. Mr. Jowett, Mr. Longden and the speaker were all of opinion that

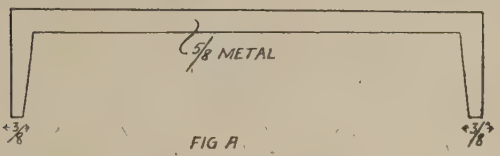


FIG A

camber experience is obtained by practice only. This is where the chart will be of great benefit with regard to the castings referred to in Fig. 2 of the Paper, the back being the thickest part of this casting and being the last to set, therefore it pulls out the ends as stated.

Mr. Sutcliffe then drew a series of sketches on the blackboard to illustrate his points. Fig. A showed a drying machine through the trough section, a type of casting required in lengths of to a maximum of 14 ft. Sometimes both ends are cast integrally and sometimes at one end

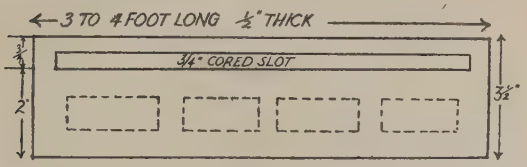


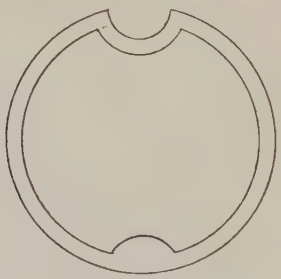
FIG B

only, because the metal is at the top side of the casting, the pattern is bedded down at both ends, varying with the length of the required casting. Fig. B shows a weaving-loom casting and resembles somewhat Fig. 2 of the Paper. Most of the mass of the metal is on one side, and although the pattern is embossed where shown by dotted lines, the casting often cracks at the point A^x, but only at one end. If the

casting be gated, utilising light, thin grey-sprey runners, this will allow of the casting cooling more equally.

Fig. C shows loom roller about 12 ft. long carrying a ½-in. metal section of which the speaker had had considerable experience, and encountered a certain amount of trouble until he added the extra metal shown to be opposite the groove. It was found to prevent warping even when using a camberless machine pattern.

Fig. D represents a trough-like casting of which he had recently made two from the full pattern.



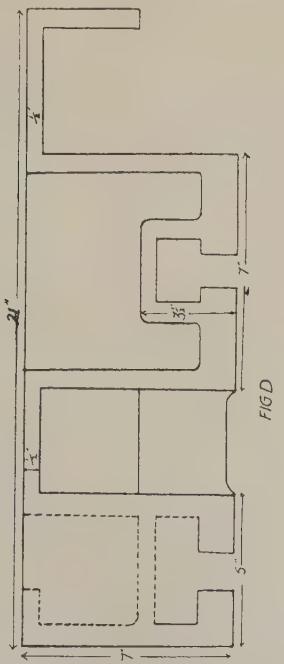
6" DIAMETER CIRCLES.
FIG C.

As it was difficult to produce adequate camber in the pattern by weighting, the job was cast without camber, but the base was bared where the T slots are shown. The sand was also removed from the slots, and castings true to pattern were produced.

Specific Gravity of Solid and Liquid Iron.

The PRESIDENT drew attention to the statement in the Paper reading "It is generally assumed that the specific gravity of cold grey iron is greater than that of molten iron. If this be so, why does cold grey iron float on a bath of molten metal of grey iron composition? Is this not conclusive evidence that cold grey iron is of lower specific gravity than molten metal of a similar volume and composition?" He did not contest that, because he did not know; he would rather ask—in the Irish way of

answering by putting another question—Was the casting smaller or larger than the pattern which had been used? He did not think the after-casting expansion of grey iron sufficient to reduce the specific gravity of the cold metal to below that of the molten. Might not the floating of the cold metal be due to the surface tension of the molten metal? In this connec-



tion he mentioned the experiment in which a needle, after having been lightly greased by the finger, was placed on tissue paper and then placed on the surface of water, leaving the paper to sink, the needle being left floating. One would not say, however, that the needle was of lower specific gravity than the water. It was a result of the surface tension of the water.

Again, if one placed cold grey iron on the top of molten metal there might be, between the clean molten metal and the clean metallic part of the cold iron, quite a quantity of other material of distinctly lower specific gravity, which would be enveloped by the molten iron and help the buoyancy.

With regard to the last experiment mentioned at the end of the Paper, he had not had time to study it seriously, but he gathered that the pith of the experiment was that the thinner bars contracted more than the larger. He would be inclined to ascertain the combined carbon and the graphitic in the two cases, because if there were more graphitic in the thicker one its average specific gravity was bound to be lower than that of the thinner one. The one which had the greater graphitic content would contract the less.

Dr. A. B. Everest asked if it had not been borne out in practice that an iron with a higher combined carbon content would have a greater contraction both before and after solidification.

The President said he was speaking of bars all of which had a similar total carbon content.

Dr. Everest agreed, but pointed out that in a casting with thin and thick sections the thin sections would contract more than the thick, the point being that they had a higher combined carbon content, but the total composition was the same. That might explain some of the facts which Mr. Longden had referred to.

The President said that that was what he meant. Was it not purely that effect?

Mr. F. Hudson said that he also had been particularly interested in the statement that the specific gravity of the cold grey iron was greater than that of molten iron, but the more he had thought about it the more he had got into difficulties. The actual specific gravity of molten cast iron was determined individually by the late Dr. Moldenke and Dr. Benedicks at different times. The figure given by Dr. Moldenke was 6.65, and that given by Dr. Benedicks was 6.66. The specific gravity of cold cast iron was 6.8

for the grey iron and 7.8 for the white iron, which, according to the text-books, again assumed that molten iron had a lower specific gravity than solid iron, and, therefore, solid iron should not float on molten iron. But we all knew that it did float on molten iron, and it occurred to him that perhaps the difference of specific gravity as between the grey and white iron had something to do with the matter. Grey iron was not so heavy as white iron. In his view, the difference lay in the fact that the carbon was in a different form. The more combined carbon there was, the heavier the iron. When iron was melted, the carbon was supposed to exist in the combined form. Taking that line or argument, if cold grey iron had a specific gravity of 6.8, then, when it was melted, inasmuch as the carbon was in the combined form, the iron should be heavier. This seemed to be another matter in respect of which the text-books were at fault.

The PRESIDENT asked whether, in connection with the last statement, allowance was made for the expansion due to heat?

MR. HUDSON said it was. One would have to allow for that, and that was another point which might be considered as well. He would like Mr. Longden's views on the matter.

MR. JOHN A. SMEETON congratulated Mr. Longden upon having endeavoured to put before the Conference in a concrete form the results of his experience concerning camber, especially in connection with the heavier type of casting. In making the heavier types of beds, which in many instances had to be made from short pieces of pattern, it was very difficult to decide how much camber should be allowed, in say, a 6-ft. length, and how much in a 36-ft. length, because there was some slight difference in the resultant structure in the longer one as compared with the shorter one. The records in the Paper would be of very great use to those controlling foundries generally. A point to be borne in mind in relation to this Paper was that the moulder was

simply given the job to do, but the foreman and the manager and the chemist controlled the iron to be used, and in 99 cases out of 100 the moulder had no knowledge or control of the iron to be used.

Usually in foundries making light castings, the patterns used were made of iron. A straight wood pattern was made first in order to find out how much camber was required. After the camber had been decided upon, a master pattern was made, with double the amount of camber, the iron pattern was made from that, and the other kept at one side in case of breakage. Those who were concerned with the making of textile-machinery castings must have some extensive data which might be handed on to Mr. Longden to add to his excellent Paper. The same remarks applied to the makers of stove-grate castings. In many cases the addition of a small lug would alter the shape of the casting entirely from the first original camber that was put into it. Thus the whole question of camber was one which required very deep thought and careful consideration, so that useful figures might be produced for future use.

Mr. B. Hird, in complimenting Mr. Longden on his courage in tackling the problem of camber, said that it was one which, like the poor, was always with us, and in the past founders had had to make the best guess they could, and try it. It was a great responsibility to decide how much or in which way camber should be put on. The patternmaker very seldom took the responsibility for camber, unless the patterns had been made before, and the responsibility was usually left to the foundrymen on the floor. With regard to contraction, he asked for Mr. Longden's opinion of the relative tensile stress, to resist shrinkage, when metal was solidifying, between two points 2 in. apart and two points 4 in apart. Would there be a greater strain at the points 4 in. apart than at the points which were only 2 in. apart.

Mr. J. E. Fletcher (Consultant, British Cast Iron Research Association) said that although there was no doubt, as had been mentioned, that the difference between the graphitic-carbon percentage in the thick and thin bars of cast iron must have something to do with this distortion, yet the curious thing was that when one was dealing with a similar problem in steel one had sometimes the same camber troubles to deal with, and it was a question then, obviously, of a difference in cooling. If all other conditions were the same, there was the graphitic-carbon problem to deal with. He recalled an experience which had occurred some few years ago in connection with the making of pump rods about 64 ft. long, in steel. They were of the old-fashioned cross-section pattern, with the two big ends, one for the beam end and the other for the pump-connecting end. The castings weighed about 8 or 9 tons each and they were to be used for deep-well pumping. There had been some hesitation as to the manner in which they should be cast. First, there was a combined runner and riser at each end of the casting, and as soon as the castings were made, one had to release the sand in front of the risers lest trouble from local cracking should occur. Although that was done, the first casting had broken straight through the centre section. There was no riser on the centre of the casting, and they had relied on the risers and heads at each end. The curious thing was that when measurements were made it was found that, whilst the contraction overall was about 10 in., the first casting had contracted equally from both ends towards the centre; there was a gap of 5 in. at each end of the casting. The next casting was run from only one end, and all the rest of the castings afterwards were successfully made in that way. Those responsible had run the castings as quickly as they dared, and all the contraction then was in the direction of the runner and riser at the one end, and there was the complete 10 in. of contraction gap at the end furthest from the runner and riser.

He had made many attempts to arrive at some method of estimating what the camber should be for a casting, but he was afraid he had had to revert to the old practical idea of making one first. A good many people would say that it became almost second nature, after one had experienced a number of accidents to avoid similar accidents in the future, but he was still in that unhappy position, and he was not able scientifically and accurately to determine what the camber should be when first applying a practical test.

In a further written contribution, Mr. Fletcher said that in his experience with the casting of both grey-iron and steel propellers of large size the distortion trouble, due to the further twisting of the blades during cooling had to be reckoned with. The expected " pitch " of the blades was not always obtained, correction in the striking-up templets for the helical surfaces having to be made to obviate this defect. The amount of correction needed could not be theoretically estimated, and only practical experience was the guide.

He had also observed camber or warping defects in long white-iron castings of unequal thickness, and here the warping difficulty was only overcome by altering the method of gating. In such cases the tendency to camber generally resulted in fracture during cooling and was influenced by the composition of the white iron.

Again, the tendency to warp or camber was seen in the forging of both steel and iron U-shaped shackles. Here the smith had to water-spray or air-blast cool the outside of the curved surface whilst bending in the hot condition so as to prevent the opening-out of the shackle during cooling and to keep the bar section from distortion.

He (Mr. Fletcher) contended that whilst in grey iron castings the difference in combined carbon contents in the thin and thick walls of

a casting influences the amount and rate of contraction and is one of the main causes of distortion or camber, the different rates of cooling of the thin and thick sections from the molten condition and through the recalescence range govern the combined carbon content, but this in turn is dependent upon the analysis of the metal. Differential rates of cooling in any casting, he contended, were primarily due to defective design, and there were few more difficult problems than those of designing castings which, owing to their contour, were naturally liable to distortion during cooling from the molten state.

AUTHOR'S REPLY.

Mr. Longden replied to the discussion. Referring to the chart in Fig. 1, he said he should have stated that the figures on the right of the chart showed the camber required. With that addition, the chart should be read fairly easily. For instance, if one had to make a bedplate 24 ft. long and with general 1-in. section, then by following the line up vertically and again horizontally one came to a camber allowance of $\frac{1}{2}$ in., if the depth of the bedplate approximated 20 in. If the depth were about 30 in., the camber requirement decreased to approximately $\frac{1}{4}$ in., and at 40 in. depth the camber allowance was about $\frac{1}{8}$ in. He had experienced the utmost difficulty in correlating the width of casting on that chart. He had had visions of constructing several other charts, but he would have needed a large number of charts in order to explain the matter as fully as he would have liked to. The chart in Fig. 1 was quite good so far as the class of work described in the Paper was concerned, and would be helpful in the making of castings of a similar nature and generally, if the generalisations on camber, as set out in the Paper, were taken account of in reading the chart. It was stated, for instance, in the generalisations, that camber allowance, other dimensions remaining constant, increased with increase in length of casting. The chart followed that out. Again, that camber allowance

increased with reduction in metal section was borne out by the tests outlined in the Paper, and also by the remarks of Dr. Everest, that the thinner sections contracted more than the thicker, and consequently there was greater distortion.

No reference to side camber was made in the Paper. This matter was far too involved for him to attempt at the moment, and he had left it out of account entirely for the time being.

Discussing the setting of patterns in the mould to give the necessary camber to overcome distortion, he said that certainly one should always lay the camber strips in the bed. He imagined that Mr. Sutcliffe had an idea that in some cases the casting was bared, but he would warn foundrymen not to attempt to bare a substantial casting. His attention had been called to a heavy bedplate, weighing something like 20 tons, which had cracked. The founders had been unable to determine the camber, and had decided to bare underneath the bottom of the casting; the result was a fractured casting. So that if one had only one section of a pattern to make a rather long casting from, the setting of the full-length bed obviated all the possible troubles; it was only a matter of moving the section of pattern as required along the arranged bed until the required length had been obtained.

Referring to his remarks in connection with chilled rolls, he said that several rolls were made experimentally. Such experiments well repaid their cost. The results of his experiments had been rather startling to him, because he had always imagined chilled rolls being fed over hours, and he had fully expected, in spite of his experiments on common iron, to find a cavity at the top end, as cast. But there was none there at all.

Commenting on the references made to his statement concerning the specific gravity of grey cast iron, he had rather thrown out this obvious fact as a bait to our eminent metallurgists, and had expected them strongly to debate the phenomena, but they had not done so. The fact

remained, that if one pushed a piece of cold or warm cast iron under the surface of molten iron it would bob up to the surface again every time. He had been careful to state that the metal, when cold, occupied a smaller volume than when hot or molten, and that cold grey iron was of lower specific gravity than molten iron of *similar volume and composition*. In his opinion, mass in grey iron had a greater effect on contraction than had the actual composition, as instanced by experiments on bars of different section. Mr. Hudson had replied to the points raised on this matter, and he was indebted to Mr. Hudson for his exposition.

With regard to the possible difference as between two sections of metal between points 2 in. apart and points 4 in. apart, the tensile strength would be less on the longer section than on the shorter.

Finally, referring to Mr. Fletcher's remarks, he imagined that in steel even the friction resistance of the flat face of a mould would cause tears and cracks occasionally.

Mr. J. G. Pearce wrote that Mr. Longden's Paper was extremely interesting and would be of very great practical value. No question was of greater importance to the founder than shrinkage and contraction. The very first investigation ever undertaken by the Cast Iron Research Association was on this question, and a casting was specially designed to show the defects in a maximum degree for the purpose of examination. Great difficulty, however, was experienced in finding foundries which could produce a casting bad enough to show the defects desired, in spite of the design. Later it was found necessary to study more fully the effects of various elements in cast iron acting conjointly, and the more recent discovery of the effect of melting conditions on the properties of the casting fills the gap in our knowledge which was required before shrinkage and contraction could be investigated on a proper basis. A general investigation on shrinkage and contraction was now contemplated by the Association.

HARDENING CAST IRON, HARDENED AND TEMPERED CAST IRON, NITROGEN HARDENED CAST IRON.

By J. E. Hurst (Member).

The capacity for hardening and the facility with which the hardening effects can be controlled is a property of metals and alloys of great industrial importance. In steels this property is one of those responsible for the wide range of utility of this material. The discovery that cast iron can be hardened by various heat-treatments which can be controlled in a like manner to those applied to the various steel alloys, has proved already to be of considerable value in industry. As experience in the processes of hardening grows and the possibilities of such hardened irons become more widely known, they will go far in extending and consolidating the use of cast iron as an engineering material.

With the exception of a few isolated examples, it has been considered impracticable to obtain, until recently, cast iron hardened to a degree of hardness beyond the limits of ordinary machinability by any other method than by chilling or adjusting the composition to provide a casting in white iron or in a martensitic condition throughout. The difficulty of dealing with such castings by the ordinary processes of machining is the obvious limitation imposed on the extended use of castings hardened in this manner.

Hardening and Tempering.

It is incorrect to say that the fact that cast iron can be hardened by rapid cooling or quenching in suitable media from temperatures above the upper critical point AC3 is a new discovery. This has been known for long enough, and in fact there are many instances where such hardening has been practised. Old encyclopædias

and pocket-books contain a variety of different recipes for hardening and case-hardening cast iron by methods in almost every case resembling those applied to steels. The hardening of cast iron by heat-treatment in this manner has never found general favour with engineers, and in fact has been considered hitherto impracticable on the probable grounds that the strength properties, both of the material and the actual castings, are impaired and rendered unreliable.

It has now been discovered by experiment that this is not the case and that cast iron of suitable composition, heat-treated in a suitable manner, can be hardened and the strength properties, rather than being impaired, can be actually improved. It is this knowledge which must be considered to constitute the new discovery in relation to the hardening of cast iron by heat-treatment. Some experimental work demonstrating this has been published in two Papers given before the Sheffield Branch of this Institute ("Oil-Hardening and Air-Hardening Cast Iron and Further Experiments on Oil-Hardening and Air-Hardening Cast Irons," published in THE FOUNDRY TRADE JOURNAL on the dates December 4, 1930, and December 3, 1931, respectively). In this experimental work a number of compositions of cast iron have been investigated, including plain cast irons of normal composition and cast irons with alloy additions. Since the publication of these results a variety of other compositions have been examined also. The important discovery arising out of all these experiments is that the hardening effect brought about by the rapid cooling from temperatures above the upper critical point in all the materials examined is accompanied by a deterioration of the strength properties. This deterioration of the strength properties is immediately restored by tempering, and for each of the materials examined there exists a tempering temperature at which the strength properties are restored to a value exceeding those of the original material in the "as-cast" condition. Thus by suitable hardening and

tempering a definite improvement in the strength properties can be obtained. In Fig. 1 a graph is drawn which is typical of the experimental results obtained and shows diagrammatically the effect of hardening and hardening and tempering on the Brinell hardness, and ultimate breaking strength. Attention has been paid to the brittleness property in addition to the ultimate strength in the experimental work already

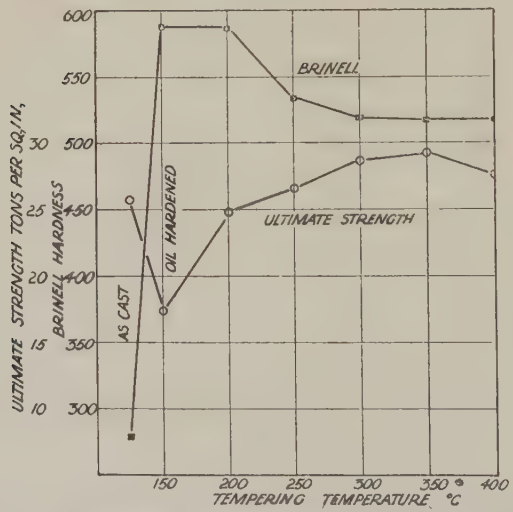


FIG. 1.—EFFECT OF HARDENING AND TEMPERING ON THE BRINELL HARDNESS AND ULTIMATE BREAKING STRENGTH OF CAST IRON.

carried out. The resilience value, the reciprocal of brittleness behaves exactly as the ultimate strength, and a definite improvement in this value is obtained due to hardening and tempering.

The further conclusions drawn from the experimental work already published are conveniently summarised at this stage:—

(1) In suitable thin sections, plain unalloyed cast iron is capable of being hardened by oil-

quenching from suitable temperatures. In a like manner plain chromium irons, plain copper irons, and aluminium-chromium irons are capable of being hardened, and the presence of nickel is not necessary to obtain the hardening effect.

(2) In suitable thin sections, the plain chromium iron appears to be accompanied by a higher level of hardness values than the nickel-chromium iron and the hardening effect is more stable on tempering.

(3) In all cases the effect of hardening is accompanied by a loss of strength properties, and in all cases these are recovered and reach a value definitely higher than the "as-cast" value after tempering.

(4) The behaviour of the various cast irons tested in respect of the En value (modulus of elasticity) after hardening and tempering is somewhat irregular. It is important to notice that on the whole this value is not very greatly changed.

(5) In thicker sections it has been shown that an ordinary cast iron is not very susceptible to hardening by quenching in oil. The presence of the alloy constituents nickel and chromium increase the hardening capacity. In the thicker sections nickel has the effect of increasing the depth of penetration of the hardening and appears to have the effect of increasing the degree of hardness obtainable.

(6) A high-hardening temperature of 920 deg. C. is accompanied by definitely inferior results both as to hardness and strength values in the samples experimented with after hardening and tempering. The lowest quenching temperatures tend towards the best results.

(7) The effect of quenching in molten salts at a temperature of 150 deg. C. in the case of the samples investigated has been shown to be accompanied by a slightly higher strength value and a slightly lower hardness value after hardening and prior to tempering.

TABLE I.—*Chemical Analyses of Nickel-Chromium Cast-Iron Bars with Varying Nickel Content.*

Sample No.	T.C.	C.C.	Gr.	Si.	Mn.	P.	Ni.	Cr.
1 ..	3.71	0.57	3.14	1.92	0.96	0.45	Nil	0.11
2 ..	3.76	0.41	3.35	1.97	1.02	0.48	1.18	0.11
3 ..	3.71	0.43	3.28	1.92	0.96	0.47	2.05	0.11
4 ..	3.71	0.36	3.35	1.92	0.99	0.49	2.97	0.15
5 ..	3.71	0.43	3.28	1.97	0.94	0.47	4.10	0.15

It is desirable to emphasise that these conclusions have been confirmed now over an exhaustive range of experiments with a variety of chemical compositions of cast irons. For the most part this experimental work has been confined to samples of comparatively thin section. The effect of hardening by quenching applied to specimens of thicker section was dealt with to some extent in the second of the two Papers referred to with the result set out in paragraph 5 of the above summary. Some further experiments of a more comprehensive nature have been carried out since, and as this is an important aspect in the application of hardening treatment to general castings, it is considered advisable to present these further results in full. The object of these experiments was to examine further the effect of hardening by oil-quenching specimens of increasing thickness and to ascertain the influence of increasing nickel contents on the results obtained. With this end in view, a series of round bars of $1\frac{3}{4}$ in., 4 in. and $5\frac{1}{2}$ in. dia., respectively, were cast. The bars were cast in metal moulds approximately 20 in. long. Five sets of bars were cast in all; the first set in a plain chromium iron and each successive set with the addition of 1, 2, 3 and 4 per cent. (calculated) of nickel to the same material. The chemical analysis (actual) of the bars in the "as-cast" condition are set out in Table I.

The Brinell hardness of the bars taken on a polished flat surface immediately underneath the outside skin in the "as-cast" condition are set out in Table II.

TABLE II.—*Brinell Hardness of Nickel-Chromium Cast-Iron Bars (As-Cast Condition).*

Dia. of bar.	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 4.	Sample No. 5.
In.					
$1\frac{3}{4}$ ..	488	555	518	291	418
4 ..	474	269	235	245	364
$5\frac{1}{2}$ ..	277	212	228	228	321

Reading these results across the tables, they clearly show the effect of increasing nickel contents, in lowering the hardness until with 4 per cent. nickel approaching the Martensitic range, the hardness undergoes an increase. Reading

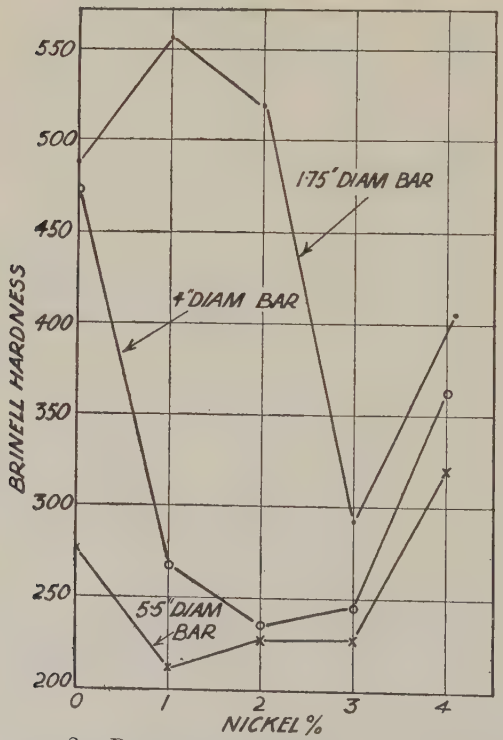


FIG. 2.—BRINELL HARDNESS OF NICKEL CHROMIUM CAST-IRON BARS, WITH VARYING NICKEL CONTENTS (AS-CAST CONDITION).

downwards, the results show the effect of the increased diameter and consequent slower rate of cooling in lowering the hardness values obtained. This is further illustrated by plotting the results in the form of a diagram, Fig. 2.

Prior to hardening the whole of the bars were subjected to a uniform annealing treatment at a temperature of 900 deg. C. Cross-sections of the annealed bars were prepared and Brinell hardness determinations taken at regular intervals from the outside edge to the centre of the cross-section. The Brinell results obtained from the outside surface of the annealed bars are shown in Table III. The annealing treatment

TABLE III.—*Brinell Hardness of Nickel-Chromium Cast-Iron Bar (Annealed Condition).*

Dia. of bar.	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 4.	Sample No. 5.
In.					
1.75..	212	217	228	207	228
4.0 ..	207	196	207	212	228
5.5 ..	179	187	196	187	217

in all cases has had the effect of reducing the hardness, even in the high-nickel-content specimens. The hardness values in the various annealed specimens across the section of the bars lie between a low limit of 149 and a high limit of 228. Whilst there are some slight irregularities, the hardness tends to diminish from the outside edge to the centre of the bars, and there is some slight evidence that the presence of nickel tends to maintain a slightly higher level of hardness in the central portions of the larger diameter bars.

After the annealing treatment the bars were hardened by quenching in oil from a temperature of 875 deg. C. and further hardness determinations carried out. These results are plotted in the diagrams, Figs. 3, 4 and 5. The diagrams show the hardness results obtained on the different nickel-content bars for each diameter of bar. In the samples containing no nickel, the maximum hardness obtained is on the outside surface. A maximum value slightly above 400 is obtained on the $1\frac{3}{4}$-in. dia. bar, and this maximum diminishes to round about 350 in the larger diameter bars. The depth of penetration

of the hardening effect in the bars containing no nickel is very small. Even in the 1¾-in. bar the hardness attained at the centre of the bar is only 250, a very small increase over the material in the annealed condition. With each successive increase in nickel contents up to 3 per cent. the maximum hardness obtained is increased. The increase in nickel content from 3 to 4 per

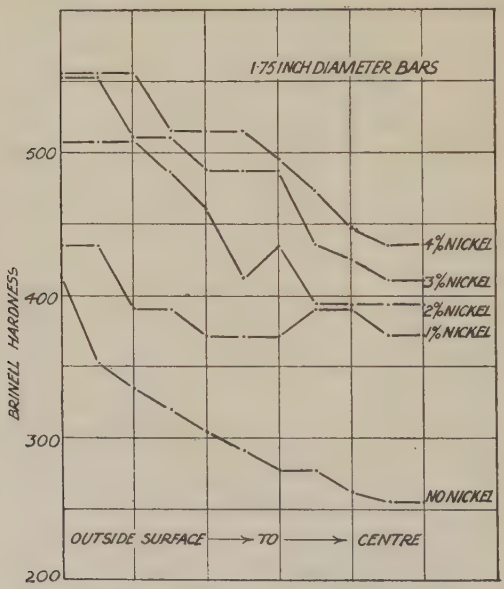


Fig. 3.—Brinell Hardness from Outside Edge to Centre of 1.75 in. dia. Bars, with varying Nickel Contents (hardened condition).

cent. is not accompanied by any increase in maximum hardness value, which remains practically stationary in all the bars at a value of 500 to 550. It is of interest to note that this maximum hardness which is attained at the outside surfaces is slightly affected by the increasing diameter of the bar, becoming somewhat lower as the diameter of the bar increases.

The effect of nickel on the depth of penetration of the hardening effect is very interesting. In the $1\frac{3}{4}$-in. diameter bar 1 per cent. of nickel brings about a substantial improvement. If the hardness at the centre of the bars is taken as a criterion of the depth of penetration it will be noticed that with the presence of 1 per cent. nickel in the $1\frac{3}{4}$-in. diameter bar the hardness at the centre is increased from 255 to 375. Further increase in nickel in this same size of

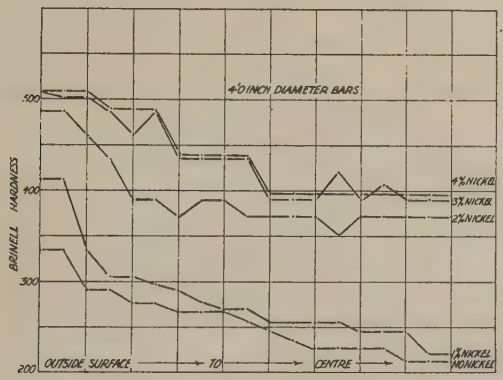


FIG. 4.—BRINELL HARDNESS FROM OUTSIDE EDGE TO CENTRE OF 4 IN. DIA. BARS, WITH VARYING NICKEL CONTENTS (HARDENED CONDITION).

bar results in an increase in the hardness at the centre up to a value of 430 with 4 per cent. nickel. Exactly the same effect is found in the 4-in. and $5\frac{1}{2}$-in. diameter bars; but in these cases the effect of 1 per cent. nickel is very small and at least 2 per cent. nickel is necessary to bring about any substantial increase in the depth of penetration of the hardening effect. With 2 per cent. nickel hardnesses of 375 and 325 were obtained at the centre of the 4-in. and $5\frac{1}{2}$-in. diameter bars respectively. With 3 per cent. and 4 per cent. nickel the hardnesses at the centre of these

same bars is raised only slightly to 390 and 350.

These further experiments demonstrate very clearly the valuable property of nickel in cast iron suitable for hardening and tempering. To

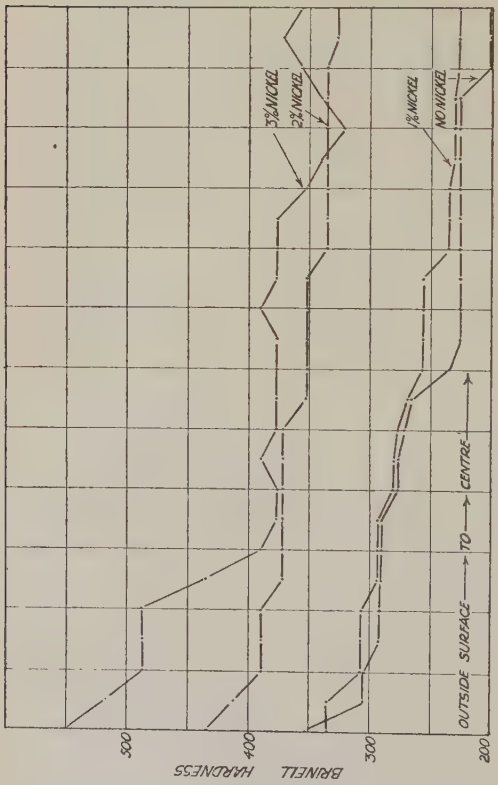


FIG. 5.—BRINELL HARDNESS FROM OUTSIDE EDGE TO CENTRE OF 5.5 IN. DIA. BARS, WITH VARYING NICKEL CONTENTS (HARDENED CONDITION).

obtain effective hardening in cast iron of the character and composition as used in this experiment, in sections up to $2\frac{3}{4}$ in. a higher percentage of at least 2 per cent. nickel is desirable.

The Production of Hardened and Tempered Castings.

The notes under this section deal with the operations of hardening and tempering. In general the procedure followed and the pre-

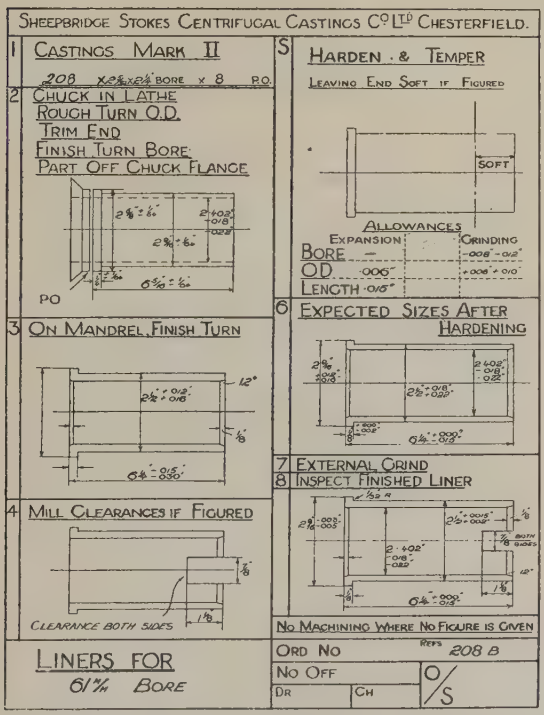


FIG. 6.—SCHEDULE OF MACHINING OPERATIONS IN THE MANUFACTURE OF HARDENED AND TEMPERED CYLINDER LINERS.

cautions to be taken in the hardening and tempering of cast iron are identical with those familiar in the heat-treatment of steel parts. In the application of hardening and tempering processes to general castings more perfect success

is ensured invariably by the adoption of some preliminary treatment with the object of removing or minimising the effect of casting or other internal stresses. It is not suggested that such treatments are essential and their adoption in any particular case must depend upon individual circumstances and experience. Two types of treatment are available, of which the first might be described as an annealing treatment and the second is better described as a stabilising treatment. This latter type of treatment has become more familiar with the

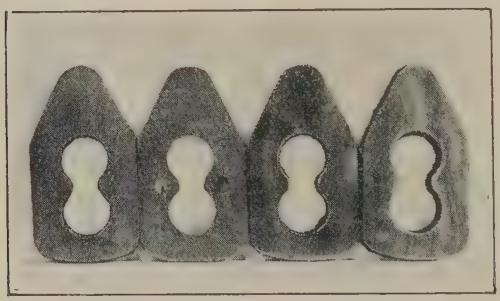


Fig. 7.—Pump Body Castings in Nickel Chrome Cast Iron for Hardening and Tempering.

extensive adoption of the nitrogen hardening process to both steel and cast irons. It can be differentiated from ordinary annealing treatments on the grounds that it is conducted at a lower temperature. The temperatures recommended generally for cast iron are from 450 deg. to 600 deg. C. The choice of the exact temperature and the period of treatment are determined by the particular circumstances, and in general the parts are maintained at the chosen temperature for a given period, and allowed to cool down either slowly with the furnace or in still air.

The common annealing treatment utilises a higher temperature, and for general purposes it can be recommended to heat the castings to a temperature of 825 deg. to 900 deg. C. followed by slow cooling in the furnace. Excessive annealing is in the case of most cast irons accompanied by considerable loss of combined carbon and furthermore it may be accompanied by serious deterioration in strength of properties. In this connection it is of considerable interest to report the following experiment.

FIG. 8.—SPECIAL VALVE BODY CASTINGS IN HARDENING AND TEMPERING NICKEL CHROMIUM CAST IRON.

This experiment was undertaken to examine the effect of drastic annealing of the casting on the hardening and tempering properties. A nickel-chrome casting of the composition recorded in Table IV was taken and the properties examined in the "as-cast" and "as-cast, hardened and tempered" conditions respectively. The results obtained are given in Table IV. The effect of the heat-treatment is exactly the same as in previous samples examined except that in this case the material undergoes a substantial drop in En values. A portion of the

TABLE IV.—*Chemical Composition.*

	T.C.	Gr.	C.C.	Si.	Mn.	S.	P.	Ni.	Cr.
As-cast ..	3.15	2.68	0.47	2.62	1.16	0.07	0.61	0.49	0.34
Annealed ..	3.19	3.18	—	—	—	—	—	—	—

	En lbs. per sq. in. by 10^6.	Tensile tons per sq. in.	Brinell. As-cast.	Brinell. Hardened.	Brinell. Hardened and tempered.	Brinell. Tempering temperature in deg. C.
As-cast	16.1	20.3	286	—	—	—
	15.4	20.5	269	—	—	—
As-cast, hardened, and tempered. Hardened in oil from 875 deg. C.	10.8	17.9	—	551	488	270
	12.3	17.6	—	518	488	270
	12.8	20.0	—	488	435	350
	13.3	21.2	—	534	460	350
	14.8	22.2	—	488	390	400
	12.9	20.0	—	518	435	400
Annealed	16.0	16.6	207	—	—	—
Annealed, hardened, and tempered. Hardened in oil from 875 deg. C.	15.4	16.4	—	488	412	275
	12.2	17.5	—	518	488	375
	—	—	—	—	—	—

same casting was submitted to a drastic annealing for a period of 24 hrs. at a temperature of 900 deg. C. The effect of this treatment as disclosed by the analysis has been to decompose the whole of the combined carbon, and this has been accompanied by a drop in both the hard-

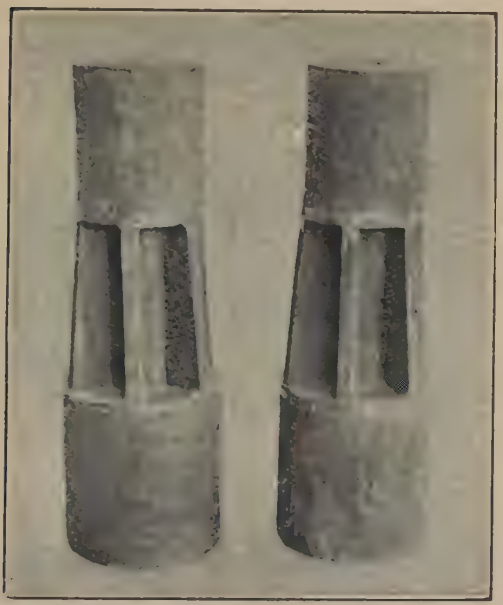


Fig. 9.—Nitricastiron Valve Castings. These Castings are Hardened, Tempered and Stabilised Prior to Machining for Nitrogen Hardening.

ness and tensile-strength values. It is somewhat remarkable to observe that test specimens from this annealed sample are susceptible to the hardening and tempering treatment, and substantial hardening is obtained. This hardening effect is accompanied by a drop in En value and a slight

recovery from the initial value of the tensile strength. The tensile strength, however, is distinctly lowered in comparison with the unannealed material. This experiment serves to show that material of this composition can sustain a drastic annealing treatment and still remain susceptible to heat-treatment. These results are of interest also from a theoretical point of view, and the mechanism of the hardening of such a drastically-annealed casting is worthy of further investigation. This is being undertaken as time and opportunity permit.

The exact procedure followed in the produc-

Fig. 10.—Nitricastiron Valve Parts. These Castings are Oil-Hardened Tempered and Stabilised prior to Nitrogen Hardening.

tion of hardened and tempered castings will depend upon the nature and particular requirements of the casting. If no machining whatever is required, then the castings can be hardened and tempered in the rough state. In those cases where intense accuracy of dimensions is not required or where the surface appearance is of no importance, the hardening and tempering operations can be carried out as the final operation after all the machining has been completed. There are many cases where the castings can be hardened and tempered in the rough state and the surfaces required to be machined finished afterwards by grinding. In the majority of cases

a certain amount of machining will be required on the rough casting prior to hardening and tempering after which treatment the final surfaces are finished by grinding. A schedule of machining operations is illustrated in Fig. 6. This is a typical operation sheet for the preparation of a hardened and tempered cylinder liner in the works with which the author is connected. The position of the hardening and tempering treatment in relation to the machining operations will be noted. This particular example is of additional interest in that it shows the provision to be made for leaving a portion of the

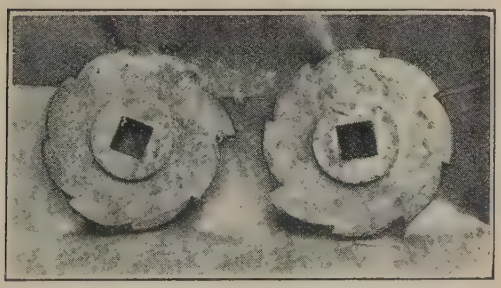


Fig. 11.—Castings in Nitricastiron. These are Oil-Hardened and Tempered prior to Nitrogen Hardening.

cylinder liner soft to allow of the cutting of connecting-rod clearances. Selective hardening of this nature can be practised readily and a variety of different methods and procedures similar to those employed in the heat-treatment of steel parts are available.

Some typical examples of hardened and tempered castings manufactured by the firm with which the author is associated are illustrated in Figs. 7 to 15. These ilustrations are intended to illustrate the application of hardening and tempering generally to sand castings. In addition, all types of cylinder liners are manufactured in hardened and tempered material,

finished hardened and tempered piston rings are manufactured now by the various piston-ring manufacturers. Some of the illustrations refer to castings in Nitricastiron. These are of equal importance in this connection in view of the fact that in the course of their manufacture they have all been oil hardened and tempered prior to nitrogen hardening. Thus they form further examples of the application of hardening and tempering treatments to cast-iron articles.

The illustration, Fig. 15, is an example of the application of the hardening and tempering

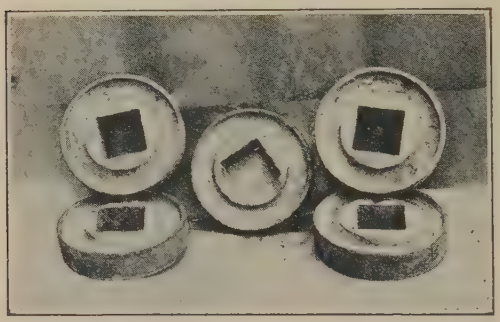


FIG. 12.—NITRICASTIRON VALVE PARTS. THESE ARE OIL-HARDENED AND TEMPERED PRIOR TO NITROGEN HARDENING.

treatment to the production of cast-iron permanent mould or die castings. The presence of hard-chilled spots and surfaces, so troublesome in castings of this nature, are removed after casting by annealing and the properties of the soft, weak casting thus obtained are restored by hardening and tempering. The experiments on the effect of annealing referred to above will be sufficient to demonstrate the recovery in properties thus obtained.

Nitrogen Hardened Cast Iron.

The application of the nitrogen-hardening process to cast iron has been developed by the firm

with which the author is associated. This process is essentially a case-hardening process in which the articles acquire exceptionally hard surfaces by maintaining them in contact with anhydrous ammonia gas at a temperature of approximately 500 deg. C. This process in its application to steel is now familiar under the name of the nitrogen-hardening or Nitrarding process, and the special alloy-steels suitable for hardening by this process are known as Nitralloy steels.

Cast iron suitable for nitrogen hardening is a

FIG. 13.—CASTINGS IN NITRICASTIRON. THESE ARE HARDENED AND TEMPERED PRIOR TO NITROGEN HARDENING.

special alloy cast iron and the best results have been obtained so far with a cast-iron alloyed with aluminium and chromium. The chemical composition and properties of aluminium-chromium cast iron suitable for nitrogen hardening have been described by the writer in a recent Paper before the Iron and Steel Institute* and have been referred to by Dr. Fry in his Paper on the nitrogen-hardening process before the same Institute. In both these Papers it has been shown that this material possesses excellent strength properties. The modulus of elasticity (En value) and Brinell hardness values are

* See FOUNDRY TRADE JOURNAL, May 5, 1932, pp. 279-282.

higher and the permanent set values lower than those usual for ordinary cast iron made to the requirements of the B.S.I. Specification No. 5004. The alloy cast iron is susceptible to heat-treatment by hardening and tempering and is also distinctly air-hardening. The treatment of this alloy cast iron with ammonia gas under the conditions of the commercial nitrogen-hardening process is accompanied by surface-hardening, and a diamond-hardness value of 982 with a penetration of 0.018 in. was obtained on centrifugally-cast specimens. A summary of the pro-

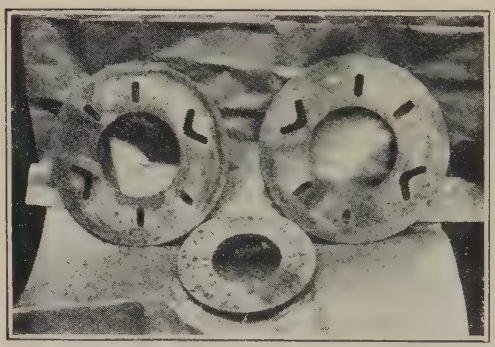


FIG. 14.—CASTINGS IN NITRICASTIRON. THESE ARE OIL-HARDENED AND TEMPERED PRIOR TO NITROGEN HARDENING.

perties obtained on centrifugally-cast Nitricast-iron is given in Table V. The microstructure of this alloy material, showing the nitrogen-hardened surface, is illustrated in Fig. 16, whilst the coherence and freedom from spalling of the nitrogen-hardened surface is demonstrated by the sharp-edged diamond hardness impression obtained on a typical sample and illustrated in Fig. 17.

The Nitrogen-Hardening Treatment.

The nitrogen-hardening process is carried out by submitting castings of the suitable alloy composition to the action of anhydrous ammonia gas

TABLE V.—*Cast No.* 147. *Centrifugal Cast Material.*

T.C.	Gr.	C.C.	Si.	Mn.	S.	P.	Cr.	Al.	V.	Ti.	Mo.
2.61 2.65*	1.38 1.10*	1.23 1.55*	2.58	0.61	0.07	0.096	1.69	1.43	trace	nil	nil

* "As-Cast" Condition.

MECHANICAL PROPERTIES.

Specimen No.	Condition.	Treatment.	Modulus of elasticity. *EN* value. 10^6 lb. per sq. in.	Tensile strength. Tons per sq. in.	Modulus of rupture. Tons per sq. in.	Permanent set. Per cent.	Firth diamond hardness numeral.	Depth of Penetration of nitrogen-hardening. In.
3	As-cast	—	22.5	24.5	39.2	2.56	418	—
4	As-cast	—	22.5	25.9	41.5	N.D.	418	—
7	Annealed	950 deg. C. followed by slow cooling in furnace	22.5	31.5	50.4	2.78	302	—
8	Annealed		23.7	29.8	47.8	N.D.	302	—
11	Hardened and stabilised	O.-Q. from 870 deg. C., reheated to 600 deg. C. for 1 hr. followed by slow cooling in still air	23.0	29.5	47.2	4.75	302	—
12	Hardened and stabilised		22.7	31.4	50.4	N.D.	364	—
15	Nitrogen-hardened	90 hrs. at 510 deg. C. ..	24.8	28.9	46.3	N.D.	962	0.016
16	Nitrogen-hardened	90 hrs. at 510 deg. C. ..	23.5	29.8	47.8	N.D.	982	0.018
17	Nitralloy steel *LK*3	90 hrs. at 510 deg. C. ..		Control	specimen		1,066	0.026

for a given time at a steady temperature of approximately 500 deg. C. During this operation, nitrogen is liberated by the dissociation of the ammonia, and this is absorbed by the alloy cast iron. The articles are allowed to cool down in contact with the ammonia and when cool are withdrawn. After this treatment the surfaces are intensely hard and no further treatment is necessary beyond the final lapping or polishing operation. The details of manipulation of the process have been fully described in

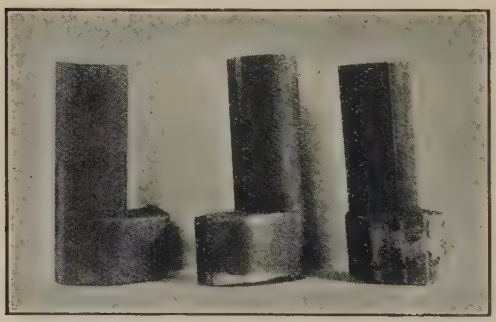


FIG. 15.—DIE CASTINGS IN NICKEL CHROMIUM CAST IRON PRIOR TO OIL-HARDENING AND TEMPERING.

various technical articles (*e.g.*, Cunningham and Ashbury, J.I.S.I., 1931, Vol. II). The furnaces used are of the electrical-resistance type and provided with automatic regulation. The parts to be hardened are placed loosely in a gas-tight box without any special packing material. The boxes are made of heat-resisting steel. The photograph, Fig. 18, shows a box packed prior to closing with centrifugally-cast Nitricastiron cylinders. The arrangement of the closed box in the furnace, with the inlet and exit tubes for the ammonia gas, is illustrated diagrammatically in Fig. 19. Anhydrous ammonia gas is supplied to the box from a cylinder of liquid

ammonia, and with the current of gas flowing the temperature is raised to and maintained at 500 deg. C. for a period of from 60 to 90 hrs.

Fig. 16. — Centrifugally-Cast Nitrogen Hardened Cast Iron, showing Nitrogen Hardened Case Etched with Picric Acid. × 200.

according to the extent of hardening required. The pressure of the gas in the box is about ½- to 1-in. water gauge. Control of the process is exercised through the extent of dissociation of the ammonia, and this is periodically checked

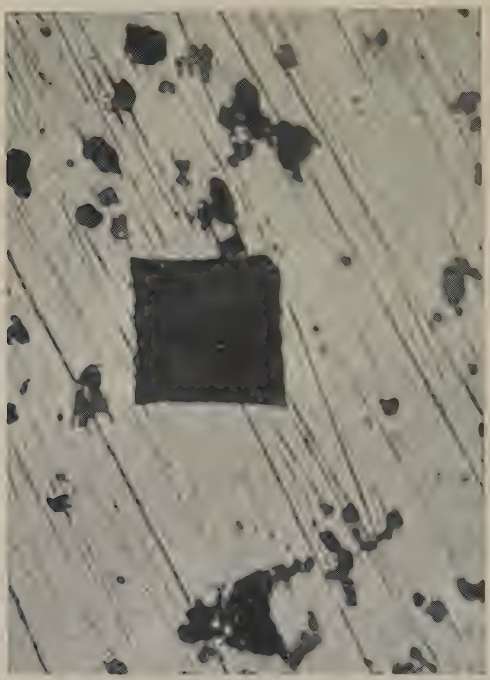


FIG. 17.—DIAMOND HARDNESS IMPRESSION ON NITROGEN-HARDENED SURFACE OF CENTRIFUGALLY-CAST SAMPLE, UNETCHED. × 119.

throughout the process and maintained at a value of approximately 20 per cent. dissociation by controlling the rate of flow of the gas.

The castings are preferably used in the hardened and tempered condition, and a stabilising treatment is also desirable where there is

likely to be any risk of distortion due to internal or casting stresses. In the majority of cases there is no necessity to adopt a special procedure of fabrication, and the hardening treatment can be applied to the heat-treated castings after finish-machining or finish-grinding. In the nitrogen-hardening process there is a slight uniform growth in the region of 0.001 in. to 0.002 in. overall on parts of solid design. This slight amount is negligible for many purposes.

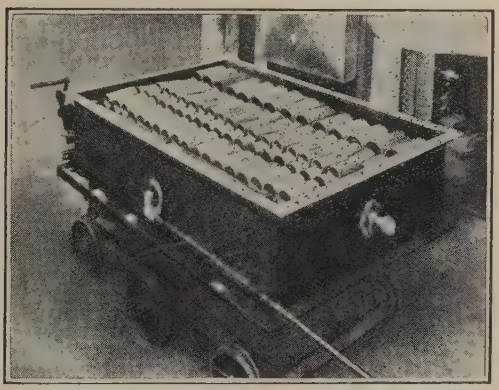


FIG. 18.—BOX SHOWING A CHARGE OF 300 CENTRIFUGALLY-CAST NITRICASTIRON CYLINDER LINERS PRIOR TO CLOSING AND INSERTING IN THE NITRARDING FURNACE.

Whilst the best results in so far as hardness and depth of penetration are obtained by Nitrarding castings with finely-machined or ground surfaces, quite satisfactory results have been obtained for the individual circumstances by Nitrarding unmachined castings in the sand-blasted condition. The results obtained are definitely inferior to those obtained with machined surfaces, but have been found satisfactory for the particular requirements.

The castings illustrated in Figs. 11 and 12 have been nitrarded after a preliminary sand-blast treatment to remove the scale occasioned

by the heat-treatment. In such cases it is advisable to take all possible steps to prevent surface decarburisation during the preliminary heat-treatment. Where necessary surfaces required to be kept soft can be protected from the hardening effect, either by tinning or painting with aluminium or other suitable paint exactly as in the case of Nitralloy steel articles. The photographs illustrated in Figs. 7 to 15 include typical examples of general sand castings which have been made in nitrogen-hardened cast iron, and will be sufficient to illustrate the potentialities of this material and process.

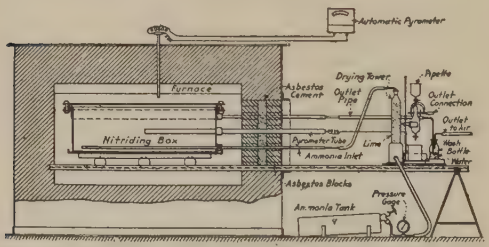


FIG. 19.—DIAGRAMMATIC VIEW OF APPARATUS FOR NITRARDING.

The application of nitrogen-hardened cast iron to the production of cylinder liners for various types of engines, compressors and pumps is of particular interest.

A large number of cylinder liners in nitrogen-hardened cast iron have been manufactured and fitted to various types of engines, including petrol engines for heavy vehicles and pleasure cars, high-speed Diesel engines and compression-ignition engines. Experimental cylinder liners have been widely distributed in various types of engines in various parts of this country and the world. These are under close observation, and most of them have now been in service for approximately two years, some of them under notoriously difficult conditions. In all cases

excellent results are being obtained, and the figures now available for liners operating in engines on road transport are in all cases upwards of 20,000 actual miles per 0.001 in. maximum cylinder wear.

The whole of this experimental and development work has been carried out in the works and laboratories of Messrs. Sheepbridge Stokes Centrifugal Castings Company, Limited, and the author's thanks are due to the directors who have generously granted permission for these results to be published.

DISCUSSION.

Mr. Wesley Lambert, C.B.E. (Past-President), who said that, having been associated for many years with one of the largest hardening and tempering plants in the Kingdom, he could claim to know something of the happenings consequent upon the rapid cooling of large masses, and particularly masses of complex shapes and unequal sections. He asked whether Mr. Hurst had carried his investigations sufficiently far to enable him to say definitely that there was no undue liability, in the case of the heat-treatment of cast iron, to the development of surface-hardening cracks. One very effective test was a drop test, in which either the casting itself was dropped from a height, or a heavy weight was dropped on to the casting. By applying such a test on a casting, after the hardening operation and before tempering it, surface cracks induced by the sudden quenching of the mass are often made evident. Simple forms do not present much trouble. Large castings of intricate shape and unequal sections when heated to a high temperature and cooled rapidly, as happens when heated masses are plunged into oil, do not always respond kindly to such drastic treatment. Skin cracks, which later develop into deeper cracks after the casting has been in service a while, are not an uncommon happening. Distortion, also, is not uncommon. Referring to the tempering of the parts after oil quenching, he remarked that the temperature was given; but

what was the method adopted? Were the parts reheated and then allowed to cool out in the air, or was cooling effected by slow cooling in the actual heating chamber?

With regard to the nitrarding process, more particularly to the extent of the dissociation of the ammonia, was the value of 30 per cent. dissociation maintained throughout, or was it boosted up as the absorption of nitrogen by the metal proceeded?

Discussing further the distortion of parts as a result of quenching, Mr. Lambert quoted his experience that the majority of thin-walled castings of complex shape, when quenched from a high temperature, were more or less distorted. Not only were castings found to be distorted when removed from the quenching medium, but even after rough machining, further distortion took place, and it was sometimes advisable to suspend the operation of finishing machining for a lengthy period. He personally had had no experience in the process of heat-treating cast iron, but he would like to ask Mr. Hurst whether, in the case of these heat-treated alloy cast irons, distortion was very noticeable.

Rate of Cooling and Strain.

Dr. A. B. Everest said that the subject of the heat-treatment of cast iron had been one of great academic interest, but, as Mr. Hurst had shown, it had now reached the stage of becoming of practical importance. Amongst the examples contained in Mr. Hurst's Paper were suggestions, covering a variety of industrial applications in which cast iron, hardened by the various methods dealt with, which would be of great future service in eliminating such persistent troubles as wear.

Reference had been made to the inclusion of various alloying materials, such as chromium, nickel, aluminium, and so on, and he asked what was the precise influence of these metals on the heat-treatment operation. In the heat-treatment of cast iron or steel, two factors were of predominant importance. They were:—(1) The

temperature from which the quenching operation was carried out and (2) the rate at which cooling took place. The temperature from which quenching must be effected in order to produce a given degree of hardness was fairly easily determined and attained, but the whole crux of heat-treatment, as applied to cast iron, was the second consideration, namely, the rate of quenching. He stated that the reason why the heat-treatment of ordinary cast iron had not, up to the present, been commercially developed was that the rate at which it had been found necessary to quench in order to attain a good result, was so rapid that the castings could not stand the strain involved in the treatment. In the case of ordinary cast iron a quench in cold water from a temperature of 800 or 900 deg. C. was needed, and, except in the very simplest shapes, ordinary castings would not stand this. The outstanding feature of the present Paper was that, by the use of alloy elements, the rate of quenching could be controlled and modified so that the treatment became applicable to quite complicated and lumpy castings.

It appeared at the moment that nickel was outstanding as the element which, in the case of both cast iron and steel, had a marked effect in slowing up the necessary rate of quenching, and he asked whether Mr. Hurst thought that chromium, in the presence of the high-carbon involved, had a similar effect. In experiments with which he (Dr. Everest) had been associated, it had been evident that if a casting of a given section was heat-treated by quenching in water, then the casting might or might not remain intact. When 2 or 3 per cent. of nickel was present, however, the rate of quenching was so slowed up that a similar hardness result could be obtained by quenching in oil, or even in an air blast. The casting, even if of quite complicated shape, was able successfully to withstand these much milder conditions. Previous experiments had shown that, with 5 per cent. of nickel, the casting was martensitic "as-cast." This result was produced simply because the rate of

quenching was so slow that it corresponded to the speed at which the casting cooled in the mould.

Heat-Treatment and Strength of Cast Iron.

A point of outstanding interest was the influence of heat-treatment on the strength of cast iron. Mr. Hurst had shown that an iron which had originally a strength of 25 tons, after quenching and tempering showed a strength of almost 30 tons. In one set of experiments recently carried out it was shown that, if the casting was tempered at temperatures superior to 400 or 450 deg. C., a condition was reached in which the hardness produced by quenching was eliminated and this property was reduced to the original level shown in the "as-cast" condition. It had been found, however, that, on tempering at these higher temperatures, the tensile strength of the iron did not fall in the same degree, and, in one case, an iron as used for heavy cylinders was alloyed with 2 per cent. nickel and 0.5 per cent. chromium and showed "as-cast" a tensile strength of 14 tons. This iron was then hardened and tempered under the normal conditions referred to by Mr. Hurst, and then showed a hardness of about 400 Brinell and a tensile strength of 23 tons.

When tempering was carried out at temperatures approaching 500 deg. C., however, the hardness figure fell back to the original 220 but the tensile strength was maintained at well over 20 tons, showing an ultimate increase in strength of about 50 per cent. If one could subject an ordinary iron to such a relatively simple treatment and increase its strength by 50 per cent., at the same time maintaining a readily-machinable structure, it would appear that this might be of commercial importance in connection with a variety of industrial applications.

A Complicated Heat-Treated Casting.

Castings which have been subjected to heat-treatment have been illustrated by Mr. Hurst, but none of them was quite so complicated as one which had come to his notice. This was a

cam about 6 in. in dia. and 1½ in. thick and carried on one side a guide standing out on legs about 3 in. long. The cam was split and the working surface was required to show a hardness of about 400 Brinell. Made up in a composition of iron as indicated above, this cam, after hardening and tempering, showed not the slightest trace of distortion and was in every way satisfactory.

With regard to Table I in the Paper, Dr. Everest asked if there was any significance in the abnormally high total-carbon figures shown. It was possible that the total-carbon content might have a very profound effect upon the manner in which these irons responded to heat-treatment. In each case shown in the Table, the total-carbon content was over 3.7 per cent., and he asked if that effect was intentional and had any direct bearing on the results.

With regard to the response obtained on the heat-treatment of castings which had been subjected to a long anneal, so as to break down the combined carbon, he asked whether, during the heat-treatment operation, conditions were not such that an appreciable amount of the carbon might return to the combined condition before quenching. If this occurred then it would afford a plausible explanation of the remarkable result shown by Mr. Hurst in Table IV.

Mr. F. K. Neath, B.Sc., referring to the tensile-strength figures quoted in the Paper, said he gathered that the bulk of them were calculated from the usual En ring test, and that they were not the results of true tensile tests as carried out normally. He asked the question because, whilst the bulk of Mr. Hurst's work had been concerned with piston rings and liners, he had shown photographs of large castings, and it would be interesting to know if actual tensile pull tests had been taken on these castings at, say, the centre and the edges. He also asked if heat-treatment affected the graphite size and distribution. The temperatures at which the castings were treated were sufficiently high to cause an alteration due to the absorption of graphite.

Use of Accelerators.

Mr. F. W. Rowe, B.Sc., said that the improvement of the wear resistance of cylinder liners was of great technical importance to the automobile industry and to all internal-combustion engine builders, and, as he understood it, the position was rather unsatisfactory. He believed all car owners were getting tired of fitting new pistons; it seemed to be much more necessary to-day than it was 5 or 10 years ago, and the problem was occupying the attention of, and worrying, a good many automobile manufacturers. Mr. Hurst had opened up a very promising field in which something could be done to help the industry.

Discussing the nitrogen-hardening of centrifugally-cast cylinder liners, he asked Mr. Hurst whether, and with what results, he had tried the use of various accelerators, such as aniline or magnesite, etc., to reduce the time necessary for the nitrogen-hardening process, applied to cast iron. Many people were applying the process to steel and were using some form of acceleration to reduce the time necessary to produce the maximum depth of case. A great disadvantage of the nitrogen case-hardening process, as compared with the more usual methods, was the large time-cycle that was involved, and it was very useful and profitable to study the effect of accelerators and to be able to reduce the time needed to obtain the maximum depth of case from about 90 hrs. to something under 50 hrs. by their use.

Mr. Phillip A. Russell, B.Sc. (Leicester), asked what were the foundry properties of the aluminium-chromium alloy. Was it easy to cast, or was it subject to great fluid contraction, or anything of that nature?

Overcoming a Dock Gate Valve Trouble.

Mr. F. Hudson acknowledged that this Paper, and previous Papers submitted by Mr. Hurst, had been already of very great help to him personally. He instanced an experience concerning some valves for Southampton Docks. They

had been made of ordinary cast iron, and had lasted exactly three months. The water used there was under high pressure, and contained a quantity of sand, so that a very erosive action had occurred, and the sand and water mixture had cut through the wedge of the valves. Following Mr. Hurst's recommendations in the Paper, it was decided to heat-treat the valves, and also to put in an alternative valve, made of high-nickel cast iron—having a 5 per cent. nickel content—and a martensitic structure. All the parts of the valves were heat-treated—the dome, the body and the wedge. First they were cast in an iron containing about 1 per cent. of nickel and 0.5 per cent. of chromium, and they were finish-machined before heat-treatment. They were oil-hardened and tempered at about 300 deg. C., and the Brinell hardness was 400. The wedge fitted perfectly into the body after heat-treatment, and there were no signs of distortion. Duplicate sets were made, and one set of castings was broken up with a hammer in order to get a rough idea of their strength, and, so far as one could see, the hardened and tempered casting was infinitely stronger after heat-treatment than before. There was no difficulty in machining. The high-nickel iron valve, which was hard as cast, was difficult to machine, the machining occupying about six hours, against half an hour in the other case.

The PRESIDENT asked if Mr. Hurst had tested water-quenching of his specimens, or whether he was afraid of cracking. He suggested this because in research work it was very often desirable to go to extremes at both ends of the line and then to converge towards an equilibrium point. He also asked if Mr. Hurst had analysed every change of relationship of combined and graphitic carbon after hardening in oil. With regard to the effect of drastic annealing, he asked if Mr. Hurst had tried two, or three or more quenchings of the material, in order to ascertain whether ultimately he could restore the condition which existed prior to the apparently destroyed condition of which he had spoken.

The elastic constants of the irons were undoubtedly high, and it would have been interesting to have noted the limits of proportionality of the material during the observations. Finally, the President asked what would be the effect of continued heating of the material which had been nitrarded. Did it lose its good qualities in any degree?

AUTHOR'S REPLY.

Mr. J. E. Hurst, dealing generally with the influence of various elements, said his experience in investigating the possibilities of heat-treating cast iron had yielded what appeared to him to be remarkable results, results which one would not have expected from one's prior training and teaching. That seemed to show that it was very dangerous to attempt to argue by methods of analogy as to the possible influence of any alloying additions to cast iron. What he meant to convey was that it would be quite possible to suggest answers to some of Dr. Everest's questions on the basis of analogy with the influence of these various elements in steels, but he wished to refrain from doing anything of that nature at this stage because he felt that only actual experiment would provide answers to these various points. As this problem of heat-treatment was only just beginning to be investigated, one could quite imagine that there was a vast amount of work remaining to be done. He hoped sincerely that other investigators would take up the question; it was only by extensive investigation that we should ultimately find satisfactory answers to questions dealing with the real influences of nickel, of chromium, of high-total-carbon content, and so on. Frankly, he could not yet give an answer to those questions, based on experiment.

Heat-Treatment Technique.

Commenting on Mr. Lambert's remarks, he said the heat-treatment of any material was accompanied by problems associated with distortion and stresses, and a practical technique had developed in most hardening shops for dealing

with the hardening of complicated parts; all sorts of dodges were resorted to in order to obtain successful results. These remarks applied to cast iron, as to other metals. There was a danger of cast iron cracking. Castings had cracked in hardening, just as forgings had cracked in hardening, and one had to use the usual methods of dealing with them; one could rely a good deal on analogy in addition to experiment for guidance in this matter.

Replying to Mr. Lambert's question as to the nature of the tempering operation, he said that in all his work up to date the whole of the tempering was done in salt baths, and the castings were cooled down in ordinary still air after tempering.

Mr. Hurst took the opportunity to express his appreciation of Dr. Everest's remarks. All he wished to say further with regard to the influence of the respective elements was that investigations were in progress having for their object the determination of the influence of some of the elements, particularly nickel and chromium. It would be appreciated that the investigations must be directed primarily with the commercial end in view, and the investigators were dealing first with the elements which were most important from that point of view, such as nickel and chromium. He hoped at some future date, however, to have the opportunity of investigating the effect of elements such as carbon, silicon, manganese, sulphur and phosphorus, all of which must have a vital influence. Very probably, the best composition of cast iron for hardening and tempering, when it was arrived at, would be something totally different from those in use to-day. Dr. Everest had made the suggestion with regard to the experiment on the drastically annealed sample and its hardening which he (Mr. Hurst) had not dared to make. It did appear that the explanation suggested was the only explanation possible, but again he would prefer not to express an opinion on that matter until more extended experimental investigation had been made.

Replying to Mr. Neath, he said that the tensile tests recorded in the Paper were all determined by the ring-test method as laid down in the B.S.I. specification No. 5,004, and the Aircraft Material Specification 4K6. He had not yet had an opportunity to investigate exhaustively the effect of heat-treatment upon the distribution of graphite.

Dealing with Mr. Rowe's question concerning the application of accelerators to the nitrogen-hardening process, he said he had not yet had an opportunity to try out any of the various methods proposed, but hoped to have such an opportunity in the future. In reply to Mr. Russell he said that the aluminium and chromium alloyed cast irons were very difficult to cast. One encountered all the difficulties that were associated with any alloy which contained aluminium. In spite of that, however, he had managed to make satisfactory castings by taking precautions similar to those taken in the casting of other aluminium alloys.

The confirmatory comments by Mr. Hudson on the application of hardening and tempering to valves were very gratifying and he was very glad to know that the results obtained by Mr. Hudson were satisfactory. A valve casting, and particularly a valve body, must be very difficult to deal with from the point of view of quenching.

Replying to the President, he said he had not seriously tested water-quenching yet. Dealing with the question as to whether he had analysed every change in combined carbon and graphite after hardening, he had not seriously investigated that aspect of the hardening problem yet. Neither had he tried more than one quenching. The effect of continued heating of the nitri-cast iron material had been investigated up to a point, as that was of direct commercial interest. Provided the temperature did not exceed 600 deg. C., continued heating applied for long periods of well over 500 hrs., had not made any difference to the hardness Further experiments on this were in progress.

FERROUS AND NON-FERROUS METALS IN THE FOUNDRY.

By W. Rosenhain, D.Sc., F.R.S.

It is probably because the industry is in the hands of different firms and is carried out in some cases in different districts that a line of demarcation has grown up between ferrous and non-ferrous metallurgy. Whilst I do not fail to recognise the differences which exist between the two branches, I have long felt that the distinction as it stands to-day is arbitrary and not only unjustified but unwise. If we confine our attention to the foundry alone we must realise that the object both of the ferrous and the non-ferrous worker is to produce a sound, strong casting of the desired shape by filling a mould with molten metal. In that one sentence so many points of similarity between the work of the ferrous and non-ferrous foundry have been summarised that it is scarcely necessary to insist further upon the point. In the present Paper I propose to consider the similarities and dissimilarities between the behaviour of ferrous and non-ferrous metals in the foundry, although I cannot hope to make my treatment of the subject by any means exhaustive. The purpose of the comparison which I propose to outline here, however, goes much further than the desire to break down an artificial barrier between "ferrous" and "non-ferrous." My experience of foundries of both types has led me to form the opinion that each has much to learn from the other, for although there are many features peculiar to any particular type of metal or alloy, there are others which relate essentially to the handling of liquid metal which apply equally to the majority of alloys. It is surprising, therefore, to find that in practice there is at present very little interchange of knowledge and experience between the ferrous and non-ferrous

branches of the industry, so that there appears to be much room for the worker in each field to learn from the other how both things may be done well and how they should not be done.

Differences in Non-Ferrous and Ferrous Practice.

Perhaps it will be as well at the outset to analyse the *differences* between ferrous and non-ferrous metals in order that we may better appreciate those problems which are common to both.

Probably the most important difference, at all events between cast iron and the non-ferrous metals, is the relatively low price of the former. At first sight this would appear to be purely a commercial question, but on examination it proves to be a very important factor. To take one point only, metal losses in the non-ferrous industries are a matter of serious importance and the methods of melting particularly are rightly designed to minimise such losses. On the contrary, in the case of cast iron the cost of melting both in regard to fuel, capital cost of furnace, labour and other charges becomes a much more serious item in relation to the cost of the finished casting. The consequence has been that in the majority of cases the cheapest and simplest type of melting furnace has been employed for cast iron with comparatively little regard for metal losses and, I fear, in some instances no very great regard for the quality of the resulting product. I am quite aware that perfectly satisfactory cast iron of high quality can be made cheaply and well in a properly designed and operated cupola furnace and, in fact, I understand that in America the use of a furnace of that type for brass melting on a large scale has been attempted. On the other hand, the electric furnace of the cored-induction type has made great progress in the brass industry and may be destined ultimately to replace all fuel-fired furnaces for that purpose. For cast iron, on the other hand, although an electric-arc furnace has been used in a few foundries and the use of the high-frequency

induction furnace is now being suggested tentatively, the melting costs in these furnaces as compared with a cupola are so high and are so important a factor in the price of the finished product that it seems very doubtful whether electric melting can make the same headway in the cast-iron industry as it is doing in connection with the non-ferrous metals.

The Case of Steel.

If, under the heading of ferrous metals, we include, as we must, steel, we meet with a very different picture. Here the value of the product is higher and the attainment of satisfactory quality both more important and much more difficult. It is not too much to say that at the present day the production of thoroughly sound steel castings of all desired sizes and shapes is an art which is neither widely known or practised, although the fine achievements of some steel foundries demonstrate that it is commercially possible. The fact that steel requires a temperature so much higher than that needed for the melting and casting of cast iron and of the great majority of non-ferrous metals not only adds to the difficulties of the founder but requires melting furnaces of a high order of efficiency. Here, again, the electric furnace, in the first place the arc furnace and more recently the high-frequency induction furnace, have made great progress, and at least an appreciable proportion of the world's output of steel castings is electrically melted. It would be interesting to analyse in greater detail the reasons why electric melting has made and is making so much progress in connection with steel and non-ferrous alloys and comparatively so little in cast iron, but the rough outline of the principal factors given above must suffice for the present purpose.

Temperature Differences.

The differences in the temperature of the molten metal which is poured into the mould bring with them corresponding differences in the moulds themselves, whilst there is also another

factor which differentiates steel in particular and also iron from the majority of non-ferrous metals, and that is the susceptibility of the former to chilling effects. It is probably not too much to say that in the great majority of non-ferrous metals the more rapidly the casting can be cooled the better the result, provided that cracking or warping do not occur. This probably also applies to castings of very mild steel, but it does not apply to a great many varieties of cast iron and to some of the harder grades of steel. Where the metal becomes hardened by chilling, either from the liquid state or by subsequent rapid cooling, a limitation is put upon the use of metal and more especially of water-cooled moulds. Some cast-iron castings are none the less made in " permanent " moulds, but I believe that in the majority of such cases the iron mould is coated with a thick dressing of a relatively poor conductor of heat. In the majority of non-ferrous metals no such thermal insulation is necessary, and the use of chill moulds is only limited by the fact that for the more complicated shapes they are difficult and expensive to produce and are apt in certain cases to require comparatively complicated mechanism to allow of the ready removal of the casting and to give it freedom to contract during cooling without stress or rupture. The use of metallic moulds, however, is subject to yet another limitation, especially where metals of high melting point are concerned, more especially if they are capable in the liquid state of dissolving or reducing the oxide coatings which normally protect the surfaces of metal moulds. A stream of very hot metal impinging upon the wall of a metallic mould is apt, first to cut away the dressing which has been applied, then to remove the natural oxide skin and to attack the metal of the mould itself, with the result that both mould and casting are damaged. Where molten steel has to be handled this is a very serious difficulty and has contributed largely to the fact that chill moulds are rarely employed in the steel foundry. The phenomenon, however,

is not peculiar to steel, but may be encountered with many of the higher melting alloys of copper and of nickel.

Sand Moulds.

If we turn from the rather special case of the metallic mould to the very general one of the sand or refractory mould we find that there is little difference in principle between the moulds and moulding materials used for cast iron and most non-ferrous metals, but that steel presents very special difficulties owing to the high temperature of the molten metal. Many of the moulding sands which are successfully employed for cast iron or for non-ferrous work are useless for steel because they are not sufficiently refractory. If fusion or softening takes place the mould itself may be destroyed or at least quantities of the surface sand become firmly attached to or even slightly embedded in the steel itself, leading to a highly unsatisfactory state of the casting with which steel founders are unpleasantly familiar. Moulding sands for steel, therefore, present problems which do not appear where metals of lower melting point are employed.

In addition to the broad differences which I have outlined above there are a number of others applicable to individual material rather than to the ferrous and non-ferrous metals as a whole. For instance, some metals fill their moulds much more rapidly and easily than others, and that is in some cases ascribable to the fact that the metal undergoes an expansion at some stage either during solidification or subsequent cooling, while, on the contrary, other metals contract seriously and continuously. The influence of gas, present in the molten metal and liable to separate from it during freezing, is very important in this connection and may in fact not only mask, but completely outweigh, any physical changes which the metal itself undergoes. Here there is probably no fundamental difference between iron and the non-ferrous metals, but, up to the present, the function of gases in cast iron

does not appear to have received the same amount of attention as has been given to it in recent years by non-ferrous metallurgists.

Sands for Moulding.

If we take in order the various processes involved in the production of a casting we shall see, from point to point, both the similarities and differences between ferrous and non-ferrous materials. Some reference has already been made to the question of moulds, but rather from the point of view of emphasising the differences between the two types of practice. On the other hand, it must be recognised that the moulds used for iron and even for steel have, on the whole, more points of resemblance with those of the non-ferrous foundry than they have points of difference. It is true that sands ordinarily used for making either green-sand or dry-sand moulds for iron and for non-ferrous purposes are different, and it would be interesting to discover the precise basis upon which these differences have arisen. I should not be surprised to find that the origin of varying practice lies largely in geographical conditions. Foundries naturally employ a sand which is conveniently situated, and although methods of studying and testing moulding sands have been developed and are gradually coming into wider use, there can be no doubt that in a great many instances the particular sand employed is a matter of traditional practice rather than of any rational choice. Experiments which I have had the opportunity of observing have shown that there is often very little difference between moulding sands derived from widely-different sources and respectively recommended for iron and for non-ferrous metals. Requirements of sufficient bonding power and of adequate permeability to gas are common to both, and the temperatures to which the sand is exposed do not differ so widely as to affect the choice of the material to any great extent. There is, however, one feature which differentiates much of the practice of cast-iron moulding from that of the non-ferrous

foundry. This is the use of a certain proportion of coal dust in certain portions of the moulding sand of the iron foundry. This is not usual for non-ferrous castings, and I doubt whether it would lead to success. On the contrary, I have seen iron castings successfully made in moulding sand entirely free from this ingredient. We have here an interesting point of difference which it should be worth while to investigate in order to ascertain whether it rests upon a sound foundation or is purely traditional. It might, at first sight, be supposed that since cast iron already contains a considerable proportion of carbon the presence of carbon in the moulding material may be desirable or at all events harmless. I have heard it suggested that the presence of the carbon in the moulding sand tends to lessen surface oxidation and decarburisation of the castings, while others claim that a combustible ingredient serves to increase the permeability of porosity of the mould.

"Flaming" Mould Dressings.

These considerations lead naturally to the subject of mould dressings and core binders. With regard to mould dressings, it is, I believe, widely thought that a so-called "flaming" dressing, which is supposed to fill a mould with reducing gas, is advantageous, both for iron and non-ferrous metals. There can be no doubt that it is highly desirable to protect the stream of molten metal, whether ferrous or non-ferrous, from oxidation during the filling of the mould. Especially where the filling process is slow and the metal enters in a comparatively thin stream, such surface oxidation may become seriously injurious. In the case of steel, it is well known that the oxides formed upon the surface during pouring react with manganese and silicon present in the metal to produce non-metallic enclosures which have no time to rise through the liquid steel in the mould and are present in the finished material. Their presence in steel, whether cast or wrought, is highly undesirable. If it were possible to protect the molten steel throughout the whole of its passage from furnace

to mould against contact with atmospheric oxygen a very decided advantage would be gained and the same applies, although perhaps to a lesser degree, to cast iron and to the non-ferrous metals. The difficulty arises, however, of carrying out such protection effectively.

In some foundries devices have been tried of causing a stream of molten metal to flow through a tube instead of an open channel or nozzle and to pass through this tube above the molten metal a current of inert or reducing gas. Unfortunately, this entails cumbersome appliances and is not readily applicable to the feeding of the mould from a ladle or crucible. The use of a "flaming" dressing is believed to furnish some protection, but I venture to doubt its efficiency. In the first place the "flaming" dressing may influence the composition of the gases present in the mould when the metal enters it, but it can scarcely protect the stream of metal before it enters the mould. Not only this, but the atmosphere produced by a "flaming" dressing is not necessarily of an adequately protective nature. It is a curious feature that metals still take up oxygen from an atmosphere containing only a small percentage of that gas or even of water vapour, in spite of the presence of considerably larger quantities of such gases as carbon monoxide or hydrocarbons. Further, the presence of de-oxidising gases prevents the formation of scale or oxide scum on the surface of the metal; yet this scale or scum acts as a definitely retarding agent upon further oxidation, and when its formation is prevented any oxygen which is present in the atmosphere is free to attack the metal with the resulting solution of the oxide in the liquid. It is therefore a matter of doubt whether a really oxidising atmosphere such as air may not be better from the view point of the total oxygen content of the resulting casting than an atmosphere rendered partially reducing by a "flaming" dressing. In regard to the decarburisation of steel in re-heating or annealing furnaces it has clearly been shown that unless

an atmosphere can be kept entirely free from oxygen and water vapour there is less decarburisation when the surface is allowed to scale in an atmosphere of air, than when it is kept comparatively clean in a "reducing" atmosphere.

Dangers from "Flaming" Mould Dressings.

Quite apart, however, from this question of oxidation the presence of a "flaming" dressing in a mould appears to me to have certain disadvantages. These arise from the fact that the dressing is not immediately decomposed when the molten metal comes in contact with it. The result is that the decomposition of the dressing under the action of heat continues well below the surface of the metal in the mould with the result that the gases given off have to find their way upwards either through the liquid metal or through the pores or vents of the mould itself. In many cases this is satisfactorily accomplished but where there are inequalities of shape there is sometimes a tendency for gas bubbles to be trapped and to give rise to unsoundness. In the case of chill moulds where there is no escape for gases except through the metal itself and where solidification near the surface of the mould commences very soon, the risk of trapping gases derived from mould dressings of this type is very considerable. These matters, however, certainly require much further study both in the foundry and by carefully designed experiments in suitably equipped laboratories. The only reason for insisting upon them here is to show that they constitute a problem common to ferrous and non-ferrous foundry practice.

Core Binders.

The question of core-binders is to some extent of a similar nature. For many non-ferrous castings cores are made of baked loamy sand, whereas for iron, it is more general to employ cores of a non-bonding sand held together by an organic binder which decomposes as soon as

the core is heated sufficiently by contact with the molten metal in the mould. A core which disintegrates spontaneously within the casting as soon as the latter has begun to set is undoubtedly advantageous, and the more so the greater the contraction of the casting during cooling. An unyielding core is very liable to cause cracking of the casting under contraction, and many devices have been employed to afford an easy means of yielding in the core. It is a curious anomaly, however, that in the practice of the non-ferrous foundry, where metals are handled which generally show a much greater contraction than cast iron, baked loam cores of a relatively unyielding character are frequently employed as compared with the disintegrating cores customary in ironfounding. This appears to be a point where exchange of knowledge and experience between the foundrymen engaged in different branches would be highly advantageous to both. Problems of ferrous and non-ferrous melting offer many other points of interest from a comparative point of view. Such questions as the "head" under which the metal is cast in the moulds, the size, shape and location of gates and risers, and many other points, naturally occur to one, but it would occupy too much space to analyse these in detail.

Methods of Pouring.

Really useful comparisons could only be made by detailed examination of the work done in foundries of different types, preferably by men expert in other branches of melting. The differences in the physical properties of the molten metals may perhaps play a part in determining the best methods of pouring them so as to enter into and fill a mould in the most satisfactory way. For instance, with some metals it would be undesirable to allow two streams passing into the mould in different directions to meet at any considerable distance from the pouring gate, since the formation of an oxide film on the surface of each stream might easily prevent satisfactory joining, so that a "cold shut" would

result. With other metals where the oxide skin is not tough there need be no misgivings on such a point. Similar considerations apply to the actual manner of pouring the metal. In some materials it is essential to secure as steady a stream in filling the mould as can possibly be arranged, since every surge and ripple is apt to leave marks of greater or lesser depth upon the surface. An outstanding example of the advantages of filling a mould as steadily and smoothly as possible is furnished by the well-known Durville process for casting alloys of copper containing certain proportions of aluminium, which give somewhat unsatisfactory billets if cast into ingot moulds in the ordinary manner, but yield the smoothest possible surface when the metal is slowly tilted into the mould by the Durville apparatus. Yet with brass not containing aluminium, the Durville method is by no means satisfactory. Such questions as the advisability of pouring the metal over the lip of a ladle or of allowing it to run through a plug-hole in the bottom of the ladle, raise somewhat similar, although different, problems.

The manner in which the metal is brought to the mould and poured into it must naturally affect the design of gates and risers, while the question of gas content and the evolution of gases from the solidifying metal introduces another factor. To some extent, no doubt, existing practice, having been arrived at by a slow process of trial and error, takes into account these difficulties. Our knowledge of these things, however, has advanced so much in recent years that the time has come when the various factors determining the production of a successful casting can be more fully analysed and improvements upon existing methods developed. It is, in fact, only when we begin to understand why we do things in the foundry that we shall really do them better and more successfully than we have done in the past.

Permanent Moulds.

The use of "permanent" moulds for both ferrous and non-ferrous castings has already been

mentioned, but the processes of die casting have also to be considered in their relation to both types of material. In non-ferrous alloys die casting proper, that is to say, casting in " permanent " moulds under pressure, has developed in recent years to a great extent, and remarkably good products are obtainable by these methods, which in many cases have opened up new uses for various alloys. Hitherto, pressure die casting has been mainly applied to metals of relatively low melting-point, although brass and bronze have in recent years been brought into its scope. The possibility of utilising the process for the casting of ferrous materials, both cast iron and steel, is probably worthy of consideration in the near future. I believe that some attempts in that direction have already been made but there are obviously serious difficulties to be overcome owing mainly to the high temperature of the molten metal, especially in the case of steel, and to the severe chilling effect which would be experienced with cast iron. We have seen in recent years, however, such marked progress in technique by which difficulties at least as formidable as these have been overcome that I should be surprised if the problem of die-casting ferrous materials should prove an exception. Possibly the development of the relatively new and hard metals consisting mainly of carbides may render possible the production of dies which will withstand even molten steel. The containers and other appliances required for injecting the molten metal under pressure also present serious problems, and there is also the difficulty of keeping the molten metal sufficiently hot up to the moment when it enters the actual die. Here, however, modern electrical methods, thanks to their great flexibility and adaptability, may help to find a satisfactory solution. Although I mention this matter very briefly, it leads to another consideration which is of general importance both to the ferrous and to the non-ferrous founder. This is the question of the selection of the right material for any particular purpose and the competition which exists between different

types of material. There are comparatively few applications at the present time where cast iron and non-ferrous castings stand in direct competition; where they do, the result is probably in the end beneficial to both, since it is only by closer adaptation both of the properties of the finished material and of the methods of production to specific requirements that success in competition of this kind can be achieved. These are things that make for general progress in both branches of the industry.

Corrosion Requirements.

A great factor in this connection lies in the increasing attention which is being given at the present time to the whole problem of corrosion. In the past it has been customary to employ the more expensive non-ferrous materials either because of appearance, facility of working, or special physical properties or because greater resistance to corrosion was required than was supposed to be obtainable with cast iron. The corrosion problem, however, is becoming increasingly important in the eyes of the users of metals and both branches of the industry are called upon to undertake developments which will meet this somewhat changed viewpoint. Here again there is some rivalry between the ferrous and the non-ferrous branches as, for example, between such things as domestic fittings cast in rust-resisting steel or those in brass or bronze with or without the protection of chromium plating. From the immediate point of view of this Paper, however, the important point is that requirements of the kind just referred to will unavoidably impose upon the founder difficulties of a nature which he could hitherto avoid to a large extent. The tendency to use an alloy or an iron of a particular character on the ground that it is easy to cast is familiar to all who are connected with the founding industry. The more stringent requirements in regard to chemical and physical properties which already exist to-day and which are certain to be insisted upon to an increasing

extent in the future, must restrict such a choice and thereby increase the technical difficulties which both ferrous and non-ferrous foundrymen have to overcome. This consideration strengthens the argument which lies at the root of the present Paper that collaboration of those working in all branches of the founding industry is highly necessary if they are to hold their own.

Competition from Forged Material.

This point is further emphasised by the competition which exists to-day between castings and parts manufactured from wrought materials whether ferrous or non-ferrous. The competition between certain types of large castings and equivalent structures fabricated by welding from rolled steel is familiar to the industry. In other directions there is a similar competition between stampings and pressings made from sheet material and castings, more especially die castings. The matter affects practically every branch of the founding industry, a striking example being the use in certain instances of cast-steel crank shafts for large engines in place of the forged shafts which are customary. The fact that such a use is possible serves to show that if the resources of the foundry are fully exploited by the application of scientific metallurgical methods combined with the best practical experience, there are fields open to the products which at the present time are scarcely touched. There is as yet a much higher degree of confidence, where highly-stressed parts are concerned, in wrought material, but there is little or no inherent reason why a thoroughly sound and properly heat-treated casting should not attain physical properties quite comparable with those of wrought material. It would, however, be necessary to improve the uniformity and complete soundness of castings, and above all their continued reliability, far beyond the level yet attained in most commercial foundries before the entire confidence of the engineer could be won. This may be a distant ideal, but it is

one towards which both the ferrous and the non-ferrous founder should endeavour to work, and they will progress the better if they work together.

Inspection of Castings.

When the casting has been taken from the mould, it has yet to undergo further processes and operations which, again, in their essence are entirely similar whatever the material of the casting. Apart from cleaning and fettling, the most important are inspection and testing. In regard to inspection, there is no appreciable difference either in the methods available or the purposes to be served as between ferrous and non-ferrous castings. Where the parts in question have to meet stringent specifications or where they are to be subjected to expensive machining processes, the most careful and exhaustive inspection is desirable, as much from the point of view of the foundry as from that of the purchaser. To have castings returned, after they have been passed by an insufficiently searching inspection, because on machining they have proved seriously defective, is almost as bad for the foundry as it is for the user who has wasted money on the earlier stages of machining. Unfortunately, it is not always possible to detect cavities or other defects if these happen to be hidden by the skin of the casting, but there are many modern methods by which such defects can be traced. Some of these, such as examination by X-rays, are probably too expensive and elaborate to be used for routine purposes. They have been used very effectively, however, as a means of ascertaining whether the method of making a casting, which has been adopted in a given case, is satisfactory. For this purpose it is only necessary to take a few samples from a batch of castings and to examine them thoroughly by means of X-rays. The occurrence of particular types of defects can usually be recognised quite readily, and they can then be eliminated by modification of the methods of pouring, gating, feeding, etc. This use of X-ray

examination for the purpose of arriving at a thoroughly satisfactory method of production before large quantities of any novel type of casting are turned out has proved highly satisfactory in a number of foundries, both ferrous and non-ferrous. There are probably many foundries of both branches where the installation of an X-ray outfit sufficiently powerful for this purpose would be difficult both on grounds of expense and of the skilled technique required for its use. This would seem to be one example where co-operative effort is desirable, and the existing Research Associations which respectively cover the ferrous and the non-ferrous field should provide the necessary facilities. Possibly one outfit for both branches of the founding industry would be sufficient for some time.

Sampling and Testing.

The subject of the sampling and testing of castings is a very large and important one, but I have dealt with it recently elsewhere and do not propose to go into details here. It is a matter which, moreover, concerns the user perhaps even more than the foundrymen and is, therefore, best discussed where the maker and the user as well as the expert in testing methods meet on common ground, as they did, for example, at the recent discussion of this subject at the Institute of Metals in London. From the foundryman's point of view, however, I would say that the establishment of the most satisfactory method of testing is highly desirable even if at first sight new methods might appear more searching and more difficult to meet. The point which I wish to emphasise is that a thoroughly sound method of testing is eminently desirable from the maker's point of view because in the first place, it gives the advantage to the better man—that is to say, to the founder who is able to turn out really satisfactory material. To those who are not as yet so fortunate as to be able to do this, a sound testing technique provides the only means of improving their product and so enabling them to compete on

equal terms with rivals who may be at the moment in advance of their practice.

Manufacturers, whether of castings or other materials, must realise that at the present time the conditions under which materials are produced and used are very different from those which were in vogue some years ago. The user possesses to-day a much better understanding both of the requirements which he may expect his materials to meet and of the methods of testing which are available. The result is that it is becoming increasingly difficult to sell materials on name or reputation and that compliance with searching specifications has to be achieved. The existing severe industrial depression has intensified this attitude on the part of the user who cannot afford to take into his shops anything that may not turn out satisfactory. At the same time the increased knowledge of the properties of materials and of testing methods has rendered these more rational and better adapted both to what the material can furnish and what the engineer really requires. The less the user knows of the properties and possibilities of a material the more likely is he to impose conditions of purchase which are unreasonable and unnecessary. Greater knowledge and greater control makes it possible in many instances to restrict specification requirements to a smaller number of essential points, although the insistence upon these becomes proportionately greater.

These are, of course, factors which apply equally to ferrous and non-ferrous materials, and it is, therefore, all the more surprising to find that there are appreciable differences in testing practice between the two branches of the industry, differences not essentially due to the varying physical properties of the materials. It is surprising on consideration to find, for instance, that whereas the transverse bending test is familiar and regularly used throughout the ironfounding industry, it is practically unknown in non-ferrous practice at the present time. Where highly-ductile materials are concerned this is, of course, natural, since the bending test does not lend

itself to materials of that type. There are, however, many non-ferrous casting alloys, particularly certain of the light alloys of aluminium, in which the degree of ductility is not very much greater than that of grey cast iron, and yet the attempt is made to measure their ductility in terms of elongation in a tensile test. The objection has been raised that the greater elasticity (lower elastic modulus) of the light alloys would interfere with the bending test because of the relatively larger amount of elastic deflection. It is, however, not at all difficult to calculate the amount of elastic deflection which a beam of given span and dimensions will give under a known load, and this can easily be tabulated and deducted from any measured deflections taken in a test.

Conclusion.

In the somewhat general discussion on ferrous and non-ferrous metals in the foundry which has been given above, I have made no attempt to go closely into detail since that would occupy a book rather than a Paper. I have endeavoured, however, somewhat sketchily to trace the points of difference and similarity between the two groups of metals with a view to stimulating interest in each branch of the industry in the work of the other, from which I am convinced that each has much to learn. But, above all, I have endeavoured to show that from the technical point of view the requirements of both branches of the industry are so closely allied that they should be pursued together. An immense amount of research work both in laboratories and in foundries is being carried on, while industrial trials of various kinds are innumerable. If one compares the published literature of the two branches one cannot but be struck by the fact that there is a great amount of duplication which could be saved if those interested in both branches could be induced to work closely together. In this country, although the Institute of British Foundrymen covers both

branches of the industry, some of our other very important organisations do not. There is in the first place the separation between the Institute of Metals and the Iron and Steel Institute, and there is also the separate organisations of the Cast Iron Research Association and the Non-Ferrous Metals Research Association. I do not wish to suggest that these various organisations should be immediately amalgamated, but there is undoubtedly a large amount of common ground upon which duplication of effort could and should be avoided, and I hope that perhaps my brief review of this aspect of the subject may do something to help developments in that direction.

DISCUSSION.

Mr. V. C. Faulkner (Past-President), who opened the discussion, said it was his experience, and he asked for Dr. Rosenhain's confirmation of it, that if one cast a metal too hot—from the foundryman's point of view—no matter what the metal might be, one would find cutaneous blowholes or pinholes in the casting, varying, naturally, with the size of the casting. If one cast either type-metal or a nickel-chrome steel ingot at too high a temperature, one would generally find these surface blowholes.

With regard to malleable, it was a fact that in the south of England it had been made during the last five or six years quite regularly, the residual heat from the electric furnace, after it had melted steel, being used as an economic means of melting the malleable.

A practice which might be extended with advantage was the use of bottom-pouring ladles. It was exceedingly common practice to use such ladles for steel casting; they were used to a very much less extent in the non-ferrous industry —perhaps in only two non-ferrous foundries in Great Britain; but he had never heard of a bottom-pouring ladle being used for making iron castings. He submitted, however, that for certain types of castings the foundryman would

have better control of pouring conditions, so far as time and quantity were concerned, if he used bottom-pouring ladles.

Mr. Faulkner then went on to refer to the phenomenon of pre-solidification of metal, the discovery of which was usually credited to Dr. Rosenhain's very erudite assistant, Mr. S. L. Archbutt. Very low-carbon steel, which was probably the most difficult metal to cast soundly —at any rate, within the whole field of his own experience—could be cast very well provided one allowed it to reach almost to a pasty stage and then remelted it. There was no need to allow it to get completely cold—that would be far too expensive—but by just altering the equilibrium the metal gave up its gas and one could cast it quite successfully even by what was known as the "hen and chickens" method. He had seen this done at Gerlafingen, in Switzerland, and the experience there had checked up with the experience he had had when working with Mr. Stobie.

Competition from Resin Products.

Another direction in which he asked Dr. Rosenhain for assistance was that of meeting the tremendous competition which the foundry industry was facing from plastics. One heard of the whole of the bathroom fittings and door furniture of transatlantic liners being made of resinous products, whereas in the past fittings of that type for a liner had meant orders to the value of several thousands of pounds to the brass-founding industry of Birmingham. In order to compete with such products, the foundry industry would like to vitreous-enamel aluminium-alloy castings. That involved a temperature of 850 or 900 deg. C., however, which was too near the melting point of the majority of light alloys. One potential solution of the difficulty was the use of beryllium. He believed that this metal was lighter than aluminium, and melted at 1,200 deg. C., which would give the necessary margin of temperature for vitreous enamelling. He

believed the price of beryllium at the moment was about £17 per lb., but there was some hope in regard to price, because only five or six years ago it was something like £3,000 per lb.

In this connection also he mentioned the dyeing of aluminium castings, and said that if they could be produced in beautiful colours this practice seemed to offer to the foundryman an opportunity to compete with plastics.

Finally, discussing the competition of welding, he said that some little time ago people had started to manufacture road rollers from weldings, but he had heard that the weldings were being returned to the shops and were to be replaced by the more rigid form of fabricated material—cast iron.

Darlington Bottom-Pouring Cast Iron.

Mr. J. H. Cooper, commenting on Mr. Faulkner's statement that he knew of no iron foundry in this country in which bottom pouring was being used, said that bottom-pouring ladles were being used very successfully in one of the largest iron foundries in the country. There was a tremendous difference between the bottom pouring of iron and steel. Iron needed to be poured as quickly as possible, but steel had to be poured at reasonable speeds. In some large steel castings made at Darlington the pouring had occupied from 7½ to 8 minutes; but in the case of some large iron castings, where it was necessary to fill the moulds in the shortest time possible, the pouring had occupied only 50 or 60 seconds. The chief difficulty was the lifting of the stopper. One had to use a plumbago stopper in a clay pot; if one used a clay pot and a clay stopper, they would very often stick together and could not be opened. The difference of time occupied in the filling of a steel mould as compared with iron was for the purpose of enabling the founder to overcome in some measure the liquid contraction which occurred. He believed that bottom pouring of iron would be successful in small work if one could prevent the slag, which in some cases was very fluid,

working down to the bottom of the stoppers. Whereas in steel casting one had only to use the ladle once and had not any more steel ready for a few hours, except in convertor practice, where metal was being tapped continually, there was sometimes very great difficulty in preparing ladles in the time available.

Copper in Cast Iron.

Mr. B. Hird said that in many foundries the old foundryman had dealt with any metals that came his way, and had had a good rule-of-thumb knowledge of both ferrous and non-ferrous. Now, recent development seemed to be linking the non-ferrous and the ferrous industries. In this connection, he instanced the addition of copper to steel in an attempt to reduce corrosion, and he asked Dr. Rosenhain if there were any possibility of adding copper to cast iron in order to secure the same advantages as when it was added to steel. He also asked what amount of copper would be present in a 0.2 per cent. carbon copper-bearing steel.

Factors in Non-Ferrous Melting.

Mr. F. W. Rowe, as one belonging to an organisation which operated large steel, iron and bronze foundries, suggested that Dr. Rosenhain, in his enthusiasm, had perhaps somewhat overemphasised the differences between steel, iron and bronze foundry practice. Such conditions as he had outlined in his Paper probably did obtain 10 or 15 years ago, but in some phases of foundry practice these differences had become less wide and anomalous. For example, in regard to sands for moulds and cores, it was quite common practice to use silica sands with a binder, commonly known as oil sands, in steel, iron and bronze founding. Steel castings were being made in moulds with what might be called oil-sand cores, and he believed that a very large part of the engineering bronze castings were made with oil-sand cores and not baked loam.

Discussing the electric melting of bronze and cast iron, he questioned Dr. Rosenhain's statement that the Ajax-Wyatt type of induction

furnace had swept the stage. At the most, up to 18 months ago 80 per cent. of the engineering bronze castings in the United States, to his knowledge, were melted in the Detroit rocking-arc type of furnace.

Dr. Rosenhain: I was referring to brass.

Mr. Rowe said he appreciated that the use of the Ajax-Wyatt type of furnace was extending in the foundry industry, but until recently the Detroit rocking-arc furnace was the one largely used in the founding industry in the United States. The fact that the use of that type of furnace had not extended to this country was not due to apathy or conservatism on the part of our bronze founders. The most serious difficulty in the extension of its use in this country was the fact that it was a single-phase furnace, and there were very few power-supply authorities who would allow a foundry to impose such a large out-of-balance load as a reasonable-size rocking-arc furnace would entail. Also, in that respect he was not entirely sure that the Americans, in their enthusiasm for electrical heating and melting, had adopted the most economical means of melting non-ferrous metals for the foundry industry. The question had been investigated seriously by many responsible people in this country, and he believed that in the increased popularity of the forced-draft reverberatory furnace we had made a distinct step forward in advance of the United States. That type of furnace, particularly for the commonly-used gun-metals and bronzes of low zinc-content, gave extremely satisfactory results from all points of view, and there was no doubt that the use of that type of furnace had been extended successfully in this country to a much greater extent than in the States.

Possibly he had misunderstood Dr. Rosenhain's reference to the cupola as not being an efficient melting unit, but his own opinion was that the persistence of the use of the cupola as a melting unit for cast iron was due to its undoubtedly very high thermal efficiency. The thermal efficiency of the cupola under good conditions was

between 40 and 45 per cent., and there were very few other melting units, apart from electric furnaces, in which anything like that efficiency was attained. The efficiency of the ordinary pit-fire or bronze or brass melting furnace, or the induced-draft crucible brass or bronze melting furnace, was between 4 and 6 per cent., and the efficiency of even the forced-draft reverberatory furnace, either coke-fired or oil-fired, was not above 15 or 20 per cent.

Mr. Rowe quibbled with Dr. Rosenhain's insistence that the term "die casting" should be applied only to die castings made under pressure. After all, the literal interpretation of the word made no reference to whether or not pressure was used. He suggested that the adjective "pressure" should be added to indicate exactly what was meant. He considered that he was justified in applying the term "die casting" to anything which was cast in a die whether pressure was used or not.

Finally, he expressed gratitude to Dr. Rosenhain for his Paper on a subject which was very well worthy of very close consideration, and he hoped the Paper would stimulate the founders to give due attention to the application of particular phases of one section of the industry to the other.

"Flaming" Dressings.

Mr. Colin Gresty, referring to Dr. Rosenhain's remarks on "flaming" mould dressings, said he gathered that that expression covered the use of coal dust in green-sand work, which was universal practice; thousands of tons were used every day. He did not find in the Paper any suggestion as to what should be used in its place. The output of green-sand castings in the making of which flaming dressings were used was such that their use seemed fully justified, and he believed that in the majority of cases there was no evidence that this was a serious cause of gas-holes. No doubt there were certain cases in which trouble could be caused in this

way, but in his view the fact that flaming dressings were used universally rather contradicted Dr. Rosenhain's remarks. He believed also that in using chill moulds for non-ferrous work it was very common practice to oil the moulds before casting. Perhaps that was not so universal as he believed it to be, but certainly he had seen it done and he presumed that the object was largely to allow the casting to strip well, due to the cushioning action of the gas produced from the oil.

Dr. Rosenhain's reference to the small differences in the temperatures to which sand was exposed in different classes of foundry work was not in line with most people's experience.

Dr. Rosenhain said that he was referring in that case to cast iron and bronze and did not include steel.

Mr. Gresty indicated that he had misunderstood the reference.

AUTHOR'S REPLY.

Oil Dressings.

Dr. Rosenhain replied to the discussion. After expressing his thanks for the reception accorded his Paper, he said the points that had been raised provided proof that there were a great many questions upon which those who had gained experience in different fields differed quite appreciable. For example, Mr. Faulkner had mentioned the casting of metal at too high a temperature. No doubt that always did cause trouble of one kind or another, but by no means always was that trouble in the nature of subcutaneous blow-holes. This latter was mixed up with the question of mould dressing. When referring to flaming dressings, he had had in mind the oil dressings on metal moulds rather than the coal dust in the green-sand moulds. In a sand mould, where there was any amount of porosity and plenty of opportunity for the gases evolved by the burning of the oil to escape, the chances of producing gas-holes in the castings were very much less than in a permanent mould.

He quite agreed that at the present time, in this country at all events, the use of oily dressings in moulds was still very widespread. He drew attention, however, to recent work, published by the Non-Ferrous Metals Research Association, on the casting of brass ingots for strip making. In that work the very deleterious effect of these oily dressings was shown, and the work had indicated how very much better results were obtained if more suitable means were adopted. The investigators had suggested a flame of oil or gas burning at the top of the mould to protect the metal as it flowed into the mould, and not having any oily material in the mould. The fact that flaming was used universally proved only one thing, that it produced results which were tolerated up to the moment. It did not mean necessarily that it was the right thing to do—although he quite agreed that anyone who wished to appear to be a reformer in an ancient industry must tread warily, because he would very often find that if he disposed of one disadvantage he would run into others which were even more troublesome, and a long and weary road had to be travelled before all of them were overcome. At the same time, it was well worth discussing and recognising the difficulties experienced with the devices now in use. He was not attempting in the Paper to lay down the law, or even his own ideas as to the right practice or even existing practice; all he had tried to do was to call attention to a few outstanding features of practice as he happened to know it here and there over a wide range throughout the world in the different branches of the industry.

The use of the bottom-pouring ladle was a matter for which he had been doing propaganda for some years; it seemed to him to be obviously the right and rational way of casting. The difficulties which arose in certain metals, he believed could be due only to the choice of bad refractories for the particular furnaces. If a clay stopper stuck in the clay lining of a ladle, it was possible to overcome the difficulty by the use of a better clay or of some different material. Plumbago

apparently could be used, but he imagined that siliceous material might be quite good. He saw no inherent reason why cast iron, or copper, for that matter, should not be poured from a bottom-pouring ladle, and the speed of pouring could also be adjusted as desired. Although he believed it was the practice to fill some moulds at an appalling pace, the ideal, from the metallurgical point of view, was to fill the mould as slowly as it could be properly filled. If one filled the mould very quickly and tried to overcome contraction in that way, one would do so at the expense of blow-holes produced in the casting. However, that was a very wide subject and he did not think he could go into it further on this occasion.

Pre-solidification.

He was very much interested in Mr. Faulkner's remarks concerning pre-solidification. If the metal did not become particularly solid it was not strictly pre-solidification; it was an approach to it, but not equally efficient. Other methods of removing gases, and which also had been developed partly by Mr. Archbutt, were to blow in neutral gases, and so on, and they were very much more efficient and cheaper; they did not occupy so much time, and did not use so much heat, and he considered them preferable to pre-solidification. He did not think anyone had attempted them in steel, but he believed it would be tried before long.

Dyeing Aluminium-Alloy Castings.

The competition of plastics was being met to some extent by the aluminium industry. The vitreous enamelling of aluminium was not very hopeful because of the low melting temperature of aluminium. The use of beryllium was not practical politics at present; not only was the metal too expensive, but it was a hard and brittle material in any form in which it was produced. It should not be, if it were produced quite pure, but it had not been so produced, and for practical purposes its use as a basis metal was out of

the question and was likely to remain so for some years. Its price was falling rapidly; meanwhile the treatment of aluminium castings and pressings by the anodic oxidation process, followed by dyeing, was giving extremely interesting results. Practically any colour could be obtained, and the resulting product was extremely resistant to corrosion. It was being used where vitreous enamels might otherwise have been used The process was being improved almost day by day and there were a great many aluminium articles which had been treated in that way and which one would never recognise as being aluminium. It was almost a pity that that was so; nevertheless, they had very great advantages and they were substantially non-conducting. One of the claims made for the Bakelite switch was that it was non-conductive, but the anodically-covered aluminium articles were practically as insulating as Bakelite. Anodically-covered wires were being used for winding transformers.

Copper in Cast Iron.

Dr. Rosenhain was unable to answer off-hand the question with regard to the amount of copper used in certain steels, but he believed the amount of copper varied a good deal according to the ideas of the producers of this material. It was possible to put in quite a large amount of copper if one desired to, but usually it was of the order of 0.1 to 0.2 per cent. There was in existence an alloy of cast iron—in the sense that it was made in the cupola—in which Monel metal scrap was mixed with pig and/or scrap, and it was extraordinarily good. It was a remarkably interesting material; it contained a good deal of nickel and copper, but, being made from scrap material, it was not expensive. It machined extraordinarily well and was very resistant to corrosion, and he imagined that it was quite a rival to brass except for its appearance; it had a dark coppery colour.

Relative Furnace Efficiencies.

Commenting upon the remarks of Mr. Rowe, he said it was always interesting to hear other

people's views, even if one did not accept them. He was glad to have been told that he had over-emphasised the difference between ferrous and non-ferrous practice, for he had been afraid that he would have been told that he had not realised how great the differences were. With regard to the Ajax-Wyatt furnace, he quite agreed that it was used mainly, though by no means exclusively, for brasses, and that the castings made from the brass were not used as castings, but for tubes and other things. Nevertheless, they were the products of the founder's art, whatever use was made of them. The Detroit furnace was used widely in America, and it had always seemed to him to be very remarkable that it should have been so successful. It was, comparatively speaking, a crude appliance, and he was not sure that in the long run we should not be all the better for not having attempted to use it in this country, owing to the conditions of three-phase supply, which were almost universal here. There was no doubt that the electric-supply authorities of this country did stand in the way of electric-furnace application in many cases, because they did not encourage the kind of load which these furnaces would entail. Steel undertakings, of course, were large enough in many cases to have their own power supplies, or at any rate to convert in such a way as not to interfere with the general system. It was true, of course, that to ask to impose a large out-of-balance load on the three-phase system was asking a great deal, but one could hardly be expected to use three furnaces at a time in order to keep the load in balance. He agreed with Mr. Rowe that the reverberatory furnace had made great progress, but he was not at all satisfied that it produced the best-finished article. The metal was exposed to prolonged contact with the furnace atmosphere, and he believed it was being found increasingly that that exposure was highly undesirable—more so in some metals than in others. Consequently, if we could find an efficient melting device in which such exposure was avoided, we should certainly

do better. He agreed also with Mr. Rowe's remarks concerning the purely thermal efficiency of the cupola. After all, he supposed the maximum thermal efficiency was obtained in the Bessemer convertor, and if one burned the fuel in contact with the metal, as in the cupola, there was a high thermal efficiency. He had in mind, however, the overall efficiency, including metal losses. Clearly the pit fire was inefficient. But until something better was available it had been the only means by which to preserve the purity of the metal. The high-frequency furnace gave us a better opportunity of doing that. He was by no means an advocate of the pit fire.

Die-Casting.

With regard to the meaning of the expression "die-casting," his quarrel was that the word "die" was misused when applied to an ordinary chill mould. A die was something used for applying pressure, and not merely a mould, and, consequently, he considered that the use of the term "die-casting" for something which was solidified in a metal mould, simply because it was in a metal mould, was a little misleading. At any rate, he considered it unwise, from the trade point of view, to apply to such castings a name which, in the interests of the trade, should be reserved for application to things in the making of which pressure was used. However, it did not very much matter whether we called these things die castings or cabbages so long as we understood what we meant.

Dealing with Mr. Gresty's reference to the temperature of sand, he said he had mentioned specifically the very high temperature to which steel-moulding sands were exposed, and the necessity for the use of very refractory sands there. In another portion of the Paper he had compared brass and bronze castings where the difference of temperature was not very appreciable.

Finally, he emphasised that the object of the Paper was not to raise controversies but to draw attention to some of the influences in adjacent fields of activity to which the foundrymen, in

the course of their busy lives, might not have much time to direct their attention.

The PRESIDENT (Mr. Stobie), dealing with the question of thermal efficiencies in furnaces, said that quite frequently he had obtained over 90 per cent. efficiency with high-frequency steel-melting furnaces, calculating on the most reliable specific and latent heats that were available for the materials dealt with.

SOME LIFTING CONSIDERATIONS IN A JOBBING STEEL FOUNDRY.

By F. J. Hemming (Member).

The lifting problems of a foundryman, and particularly a steel foundryman, are amongst the most important which he has to face, and the author has reached the conclusion that no set of lifting conditions can ever be perfect for the jobbing steel casting manufacturer. If, however, we continue to examine our difficulties and take steps to improve them, it becomes a simple matter to find points in our plant which lend themselves to better handling facilities, and each one done brings us nearer to the impossible ideal.

The difficulties of the British steel founder during the last decade have been very different from those of his American and Continental rivals, because his market has been much smaller and far more miscellaneous. It is to the miscellaneous foundry that the writer's considerations are directed. Whether the foundry be large or small, whether it caters for large or small castings, an enormous amount of material has to be lifted to produce 1 ton of steel castings.

The author has seen it stated at various times in American papers that 150 tons is a good average weight of lifted material to consider in the production of one ton of steel castings, and, whilst a figure of an accurate nature is almost impossible to obtain, some data we have worked out in our own works shows that 100 tons may be considered a very low estimate. It is possible to obtain fantastic figures on exceptional types of work, but whether one takes minimum or maximum figures, it cannot be denied that lifting power and its application is one of the most important factors in economy of production, if indeed it is not *the* most important.

If the foundryman is faced with lifting his 100 tons of material for his one ton of castings, what material is he lifting and how can he economise?

Figures will show that 75 per cent. of the lifting power is completed by the time the casting is handed to the fettling shop, so that it is in the foundry where economy is more easily available. In the foundry it is not an easy matter to arrive at an analysis of lifting figures, but the writer has endeavoured through observation and data to divide this 75 per cent. of lifting power between "sand and equipment" under one heading; and "metal" under another; and these seem to work out at an average of 60 per cent. under "sand and equipment" and 15 per cent. under "metal."

Cost of Crane Handling.

With labour costs in a steel casting about 50 per cent. of its total cost, the most vital consideration of all is the combination of labour and lifting power. One must dismiss the cost of lifting power without much thought, because the cost of running a 15-ton crane is only about 3d. per hr. for power and about 6d. per hr. for depreciation and maintenance on a liberal scale. What therefore really matters is lay-out and flexibility of lifts. Ample floor space or economy of floor space suggests itself as being a special lifting consideration. Labour, which is a vital cost, is then given the highest possible mobility and the least wastage of time. The question of obtaining flexibility of lifting power is extremely difficult for the foundry whose variety runs from a 10-ton casting to a few hundredweights, but even in old-established foundries it is possible to introduce methods of lifting power which do not demand high capital expense.

One must remember that on a 10-ton casting there is a range of lifts from possibly 25 tons to a few hundredweight; and on a small casting there may be a range of lifts from 20 tons downwards, with the majority of these on the smaller

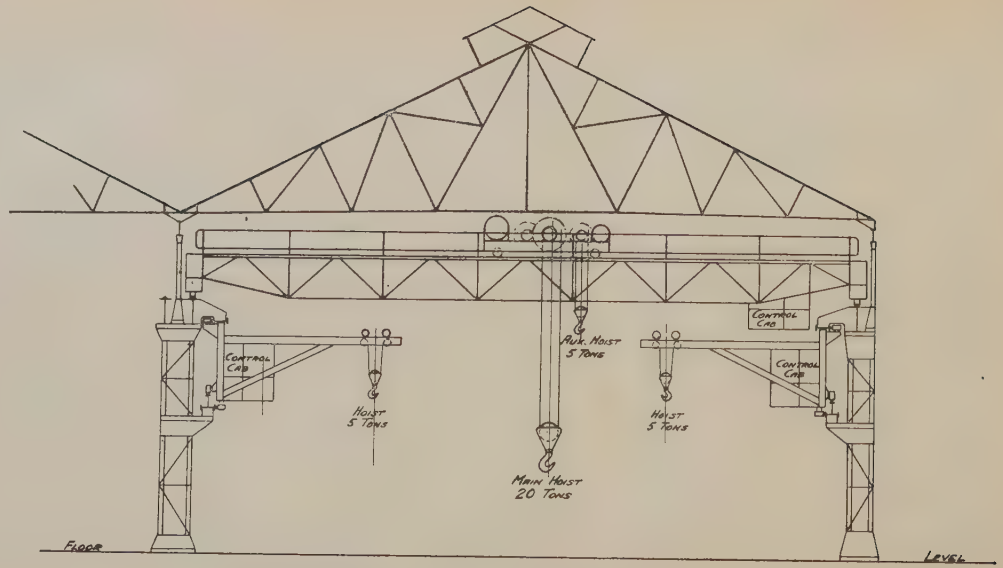


FIG. 1.—SECTION THROUGH BUILDING SHOWING RELATION OF RIGID JIB SIDE TRAVELLING CRANES TO OVERHEADS.

scale. On every day of production it is possible to produce innumerable situations which occur, but in order to meet this wide range of lifting power on jobbing work, the writer takes the liberty of illustrating the latest developments of a lifting organisation in one of the foundries of his company, which, if examined closely, will show that it gives greater freedom of movement (Fig. 1).

Speeds Utilised.

The advantages of this system are such that it is very seldom labour is waiting for a lift by reason of the combination of the overhead crane with the two rigid side gantry-cranes. The side gantry cranes are limited to 5-ton loads, but it is found that 90 per cent. of the lifts of the area which they cover are met by them. The overhead crane, which will be observed, is provided with an auxiliary hoist for the small loads.

The speed of the main overhead cranes are as follows:—

Main Hoist.—20 tons at 12 ft. per min.
,, 10 tons at 20 ft. per min.
Auxiliary Hoist.—5 tons at 40 ft. per min.
,, 2½ tons at 50 ft. per min.
Cross Traverse.—80 ft. per min.
Longitudinal Travel.—250 ft. per min.

Apart from the usual magnetic brakes, the hoists on this crane are fitted with steady lowering brakes which prevent acceleration when lowering. This is an essential feature in foundry work.

Fig. 2 shows the area which this system will cover. In any foundry there is a good deal of immobile material, and this is stored in the centre away from the lifting activities so that that fullest possible use is maintained on the active area. Whilst the above lay-out may be argued as suitable for a foundry operating on a wide variety of production, there are other simpler suggestions which can be considered and carried out in lighter shops.

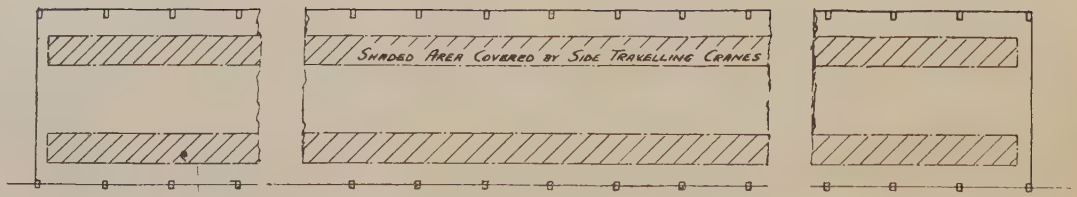


Fig. 2.—Ground Plan of Building showing Floor Area covered by Rigid Jib Side Travelling Cranes.

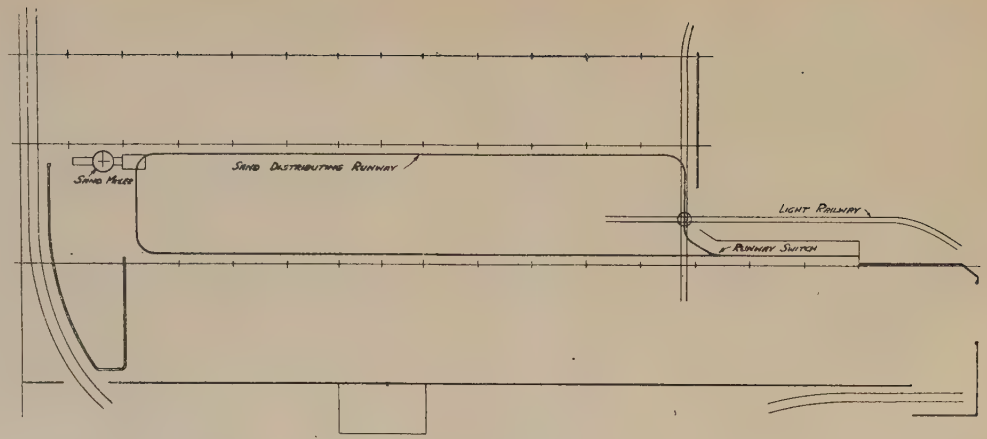


Fig. 3.—Ground Plan of Building showing Lay-out of Distributing Runway for Moulding Sand.

Runway Services.

In Figs. 3, 4 and 5 the writer has shown a light runway service which has been introduced for the production of light miscellaneous castings, the term "light" referring to castings varying from 5 cwts. to a few lbs. In a foundry of this character it will be found that lifting power is not so much a matter of overhead arrangements, and the chief commodity which requires rapid transit is the sand. This Paper is not intended to discuss the merits or demerits of a conveyor system, but to stress the necessity for possibilities of improvement to

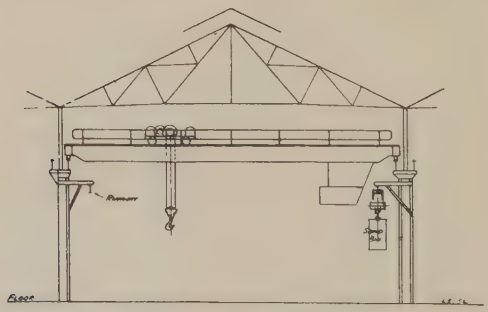


FIG. 4.—SECTION THROUGH BUILDING SHOWING RELATION OF SAND DISTRIBUTION RUNWAY TO OVERHEAD CRANE.

lifting problems. By the introduction of a separate sand service shown above, it has been possible to maintain continuous service to the moulder without any handicaps during the day, such as casting periods when the overhead crane will be engaged. This arrangement can be introduced into almost any foundry.

These notes have all tended in the direction of the combination of lifting power and labour, but it should not be overlooked that lifting power has some bearing on quality of production. Amongst these, and one which the writer thinks is very often neglected, is the question of smooth

running. Any jerking in a crane not only produces abnormal stresses in the crane structure, but also is liable to cause damage to its load, which more often than not is of a delicate nature, such as a mould or core.

Experiments are being made at the present time to eliminate every possible source of jerking by a system of clipping the rails to the gantry in such a way as to allow a longitudinal expansion and contraction due to change in temperature and by electrically welding the rail joints and grinding these level. Smooth running materially assists the work of the maintenance engineer. In any foundry, maintenance costs of lifting

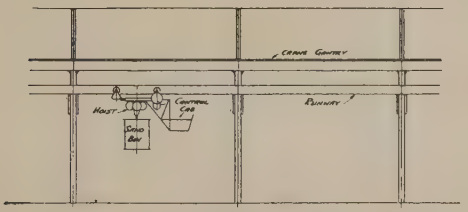


Fig. 5.—Elevation of Runway showing Hoist.

power are higher than those working under cleaner conditions. It cannot therefore be pressed too much that one ought to see that cranes or their equivalent are designed so that a minimum of time takes place in the renewal of any wearing parts.

Conclusion.

In conclusion, the title of this Paper was merely chosen to draw the attention to the large amount of lifting work which a steel founder has to perform. Each must solve his own difficulties from his own individual experience. In the main it is set out to illustrate two simple improvements which has been the outcome of experience—(1) being the introduction of greater flexibility of lifting power in a heavy foundry, and (2) a simple expedient to meet the most

pressing requirements in a light foundry. In the provision and application of lifting power there is an infinite field of possibility in every steel foundry.

DISCUSSION.

In the absence of the author, the Paper was introduced by Mr. R. Wilson.

Mr. W. R. Cooper, speaking on the diagram showing the ground plan of building and lay-out of distributing runway for moulding sand, said that there was a danger when the foundry was working at full pressure and the mill was turning out sand as fast as it could be worked, the crane which carried the sand on this runway was apt to be over-worked. When the crane had to travel from the mill to the far end of the shop there must be occasions when it came back unloaded and that was a matter for organisation to see that no time was lost. There were occasions when most of the moulders were using sand as fast as it could be produced and would not require the overhead crane. It would thus be standing idle while the runway crane was being overworked.

Mr. Wilson said that this lay-out was designed purely for the distribution of sand, and it was simple organisation with sufficient equipment of bins so that there could be a continual supply of sand to the moulders. The side cranes in Fig. 1 were put in after the shop was designed. It was found that practically 90 per cent. of the lifts could be carried out by these side cranes which had full control of 80 per cent. of the width of the shop.

HIGH-TEST CAST IRON IN THE UNITED STATES OF AMERICA.

By R. S. MacPherran * (Milwaukee Ill.).

(American Exchange Paper.)

The purpose of this Paper is to give a short description of the present status of high-test cast iron in the U.S.A. It is practically impossible in one article to list every phase of this product or to discuss all the various applications in the many companies using it. In place, therefore, of a general description covering to a limited extent all conditions it was considered more satisfactory to give a few specific and typical cases where this iron is being successfully used. There is no standard quality for high-test iron and no specifications covering recent developments. Various foundries adopt the material and practice best suited to their own needs. The subject is a very live one with constant change and improvement. Any Paper written at this time (January, 1932) may not contain all the latest developments in effect at the time it is presented.

There has been in the past few years a marked tendency toward specialisation. One foundry will specialise in automobile heads and cylinders, a second in pistons or rings, a third perhaps in brake-drums, etc. This specialisation has been assisted by two factors. First, the great production demand of the automobile industry, and second, the development of the electric furnace. Of this latter it is estimated that over 80 have been installed in this country for the production of commercial iron-castings. This estimate was reported by Mr. W. B. Wallis, Pittsburgh Electric Furnace Corporation. In describing these processes no attempt will be made to go into the theory of high-test iron, and as far as possible statements will be confined to actual experience and results.

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Definition of High-Test Iron.

In discussing this subject a field must first be defined which covers high-test cast iron as apart from the irons of lower strength. For the purpose of this article it was decided to include under this heading only those irons breaking higher than 20 tons tensile strength per sq. in., and that this test should have been made as far as possible on test specimen machined from the old standard A.S.T.M. arbitration test-bars. These bars were cast $1\frac{1}{4}$ in. round in dry sand or cores and are broken transversely between 12-in. supports. Unless otherwise stated tensile-specimens were machined from the broken transverse bars in accordance with the sketch, Fig. 6.

Processes Used.—In general high-test iron is made by one of the following processes:—(*a*) Electric furnace (with or without duplexing from cupola); (*b*) air furnace (with or without duplexing from cupola), and (*c*) cupola.

Electric Furnace Processes.

The electric furnace either melting with an initial cold charge or duplexing with the cupola melting, lends itself especially to the continuous production of small castings, usually automobile, and, therefore, does not always go into the field of highest strengths. This is, of course, for commercial reasons only, as this process can be adapted to any kind of iron desired. The details of this operation and the results therefrom are very well shown in the recent Papers on this subject read before the American Foundrymen's Association and other organisations and will not be described here in great detail.

Automobile Cylinders and Heads.—One installation using a 3-ton furnace specialises on automobile cylinders and heads. The regular operation is continuous. The iron is melted in a 48-in. cupola and tapped into the electric furnace, thus replacing at regular intervals the iron drawn off for pouring. When work is slack the electric furnace is used to melt from cold charges. A typical cold charge is 7,700 lbs. of cast-iron borings, and 3,000 lbs. of cast-iron scrap, with

2,800 lbs. of baled-sheet steel. When duplexing through the cupola scrap iron comprises the bulk of the charge with between 20 to 30 per cent. of bundled sheet steel added in the electric furnace. In this way is avoided the loss in melting bundled sheet-steel scrap in the cupola and also there is obtained the desired reduction in carbon. The cost of material used in either method is always low. In 1930 the cost to this plant of their iron in the ladle when duplexing was about £6 1s. 4d. per ton. This includes all materials, power, interest, depreciation, and all labour, including that of pouring. When alloy additions are made this cost is, of course, increased.

Recent tests of arbitration test-bars made by this company to represent automobile work show as follow:—

Bar No.	Transverse load in lbs.	Deflection in in.	M.S., tons per sq. in.	Brinell hardness.
1	5,430	0.17	24.0	248
2	4,850	0.15	21.6	241

The analyses of the bars gave:

	Bar No. 1.	Bar No. 2.
T.C.	3.02	2.94
Si	2.36	2.41
Mn	0.82	0.85
S	0.086	0.079
P	0.13	0.17
Ni	0.44	0.50
Cr	0.37	0.31
Mo	0.58	—

Both a high impact value and an additional refinement of grain is claimed for this iron due to the superheating given it in the furnace. The photomicrographs of Fig. 1 are of this iron.

Brake Drums.—A second installation makes brake drums, and a quotation from a letter descriptive of the production reads:—

"We take our cupola iron and put it into Detroit electric furnaces, add sufficient steel to give us a white fracture and proper carbon con-

tent and graphitise in the ladle. Brinell specifications on this iron are from 223 to 262. The tensile strength ranges from 22.3 to 26.7 tons per sq. in., and the approximate analyses are as follow:—C.C., 0.50 to 0.70 per cent.; Gr., 1.80 to 2.00; Si, 2.10 to 2.40; Mn, 0.30 to 0.50; S,

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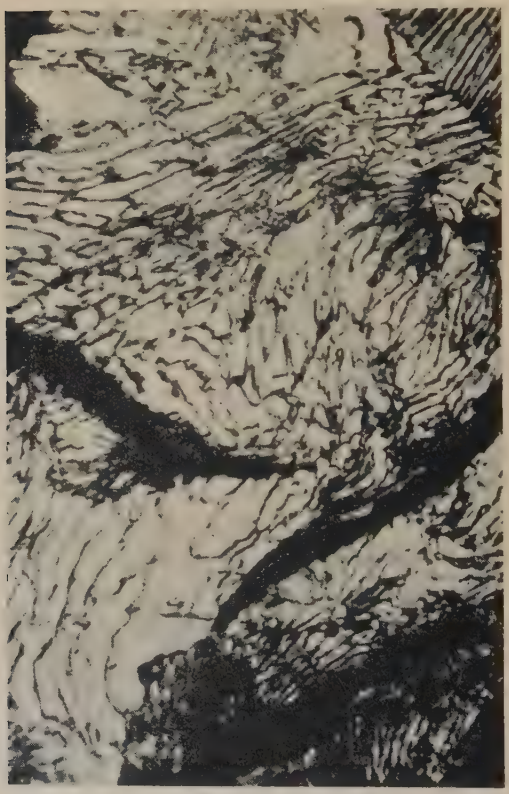

(1A).

FIGS. 1A AND 1B.—ELECTRIC-FURNACE IRON: Si, 2.36; Mn, 0.82; S, 0.059; Ni, 0.44;

0.09 (max.); P, 0.20 (max.); Mo, 0.40 to 0.60 per cent.

"We have had test-bars break as high as 35.7 tons per sq. in. on this iron, but, of course, the average bar does not ordinarily exceed 29.0 tons."

Unetched, × 100.

(1B).

24 TONS TENSILE AND 248 BRINELL. T C, 3.02; CR, 0.37, AND MO, 0.58 PER CENT.

Cam Shafts.—A third company reports on the manufacture of cam shafts for automobile work in the following terms:—

"Electric furnace iron is used. The cam shafts are not heat-treated, but are made with or without a chill as desired. Arbitration test-bars are used (12 in. between supports), and below are typical figures:—

"Transverse strength: 6,000 to 7,500 lbs.

"Tensile strength: 24.5 to 26.7 tons.

"Impact: Over twice that of ordinary cast iron.

"Hardness: Not chilled, 300 Brinell.

"Hardness: Chilled, 600 Brinell.

"Torsion: Equal to that of came-shaft steel.

"Wear: Remarkable wearing qualities.

"Cams running under conditions equivalent to 120,000 miles, at a speed of 90 to 100 miles per hr. show no appreciable wear."

Air Furnace Processes.

There are many installations of the air furnace using either cold stock or with duplexing from a cupola. Here also the grade of iron produced is dependent upon the demand as iron of practically any composition may be made in this manner. In fact, both the electric furnace and air furnace readily lend themselves to the production of low-carbon iron, and low-carbon iron is the prime requisite of high-test iron. Some air furnaces whose main demand has previously been for malleable-iron castings, are now using their excess capacity for making high-test iron.

At least three methods of procedure are now in operation:—(1) Making up the entire heat of a composition suitable for grey-iron castings of high strength; (2) adding ferro-silicon or other graphitisers in the ladle to part of a regular heat of "malleable iron." The remainder of the heat may be used for normal malleable-iron castings if desired; and (3) making the heat

of hard iron somewhat the same composition as used for malleable and then heat-treating all castings. In this procedure the castings are usually small and the carbon as cast is combined.

Tensile strengths of 26.7 to 49.1 tons per sq. in. may be so obtained with various elongations up to 15 per cent., depending on the heat-treatment. From the many such treatments in use only two will be described.

(*a*) The photomicrographs (Fig. 2) show irons where the castings and test-bars were heated to 926 deg. C. and held at this temperature for 20 hrs., then cooled in air, reheated to just below the critical temperature and held 20 hrs., then cooled in air. A shorter hold would mean a higher strength with less ductility, but with a 20-hr. hold the desired results were obtained. The spheroidisation of the cementite should be noted. The view at 2,000 diameters was taken between carbon spots which appear in the field as in malleable iron.

Features of this iron were:—Carbon, 2.29 per cent.; silicon, 1.11; manganese, 0.85; sulphur, 0.089; phosphorus, 0.18; tensile strength, 33.4 tons per sq. in.; elongation, 14 per cent. in 2 in.; reduction in area, 18 per cent.; Brinell hardness, 179; Rockwell hardness, B90.

(*b*) The photomicrographs (Fig. 3) were from an iron where the test-bar was held at 926 deg. C. for 8 hrs., air-quenched, reheated to 648 deg. C. for 15 min. and oil-quenched. Details of this iron were:—Carbon, 2.34 per cent.; silicon, 1.37; manganese, 0.37; sulphur, 0.08; phosphorus, 0.18 per cent.; tensile strength, 47.8 tons per sq. in.; elongation, $2\frac{1}{2}$ per cent. in 2 in.

No special alloys were used to obtain the above results. All test-bars referred to were A.S.T.M. standard malleable-iron test-bars cast $\frac{5}{8}$ in. diameter round and broken in the rough. There was, in all cases, a slight decarburisation on the surface. All analyses, hardness tests and micrographs were taken from the centre of the bar. The first of the above treatments is now in commercial operation under Patent claims.

The latter is more or less tentative. There would seem to be a field here for development and one in which the alloys might be of service. The low cost of steel castings, however, may limit this process.

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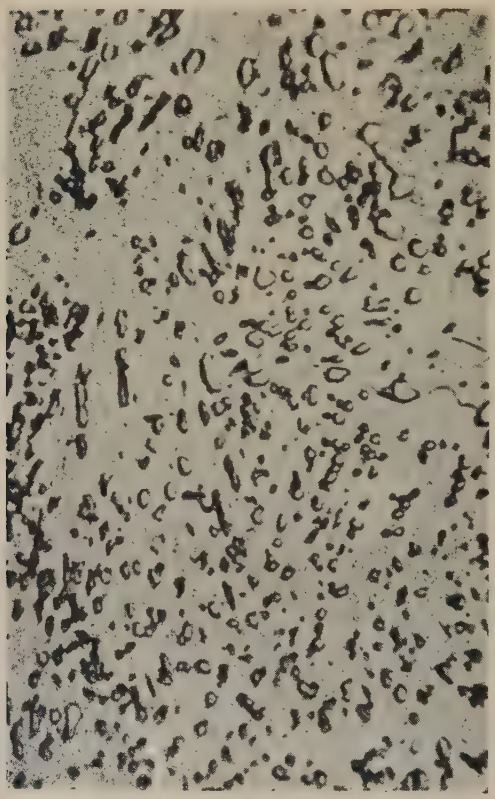

(2A).

FIGS. 2A AND 2B.—AIR-FURNACE IRON (SPHEROTION (2 IN.), 14 PER CENT. REDUCTION OF POSITION: T.C., 2.29; Si, 1.11; Mn, 0.85;

Mechanite.

Reference may be made here to "Mechanite," for which high physical values are claimed. Mechanite cast iron is made in the cupola, electric and air furnace, and involves the use

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(2B).

DISED). TENSILE STRENGTH 35 TONS. ELONGA-AREA: 18 PER CENT. BRINELL NO.: 179. COM-S, 0.089, AND P, 0.18 PER CENT.

of calcium silicide. The Meehanite process covering the use of basic earth silicides is patented in both this and European countries. When made in the cupola the process makes use of over 75 per cent. steel scrap. By the technique of manufacture and the application of the process of decomposition of excess carbides and controlling the physical constitution of the remaining carbides, metallurgical control is positive. In other words, it is claimed that not only does the process accurately control graphitisation and produce a given graphite content at will, but the form of the graphite is equally well under control no matter the size of section of the casting.

Ermalite.

The metal "Ermalite" should also be mentioned. This also is a patented process which does not require heat-treatment. It is made in an air furnace of the reverberatory type and melted in baths of 50 to 60 tons per melt. Representative physical properties which have been reported are as follow:—

Ultimate strength, tons per sq. in., 23.2 to 29.0.

Per cent. elongation in 2 in., 1 to 2.

Arbitration bar transverse test, 12 in. span, 5,000 to 6,000 lbs.

Total deflection at centre, inches, 0.35 to 0.45.

Brinell hardness ranging between 230 to 240, yet this iron is comparatively easy to machine, being slightly tougher than grey iron.

The average chemical composition of this metal is that of the following analysis:—T.C., 2.40-2.60 per cent.; Gr., 1.60-2.00; C.C., 0.60-0.80; Si, 1.90-2.00; Mn, 0.40-0.45; S, 0.07-0.09; P, 0.15-0.17 per cent.

There are other similar patented processes which could be described, but the above are believed to be sufficiently representative to serve as illustrations.

Etched, × 2,000.

Fig. 3.—Air-Furnace Iron (Hardened and Tempered) heated to 925 deg. C. for 8 hrs, and quenched in Air; reheated to 650 deg. C. for 15 min. and quenched in Oil. Tensile Strength, 47.8 tons, and Elongation in 2 in., 2.5 per cent. Composition: T.C., 2.34; Si, 1.37; Mn, 0.37; S, 0.08, and P, 0.18 per cent.

Cupola Processes.

The practice of adding steel to cupola mixtures is, of course, an old one. As service requirements became more severe, the percentage of steel was increased until in 1913 the author's

Etched, × 2,000.

(4A).

FIGS. 4A AND 4B.—CUPOLA IRON AS CAST. TEN COMPOSITION: T.C., 2.64; Si, 2.14; Mn, CENT., AND Mo, NONE.

cupola record shows that a mixture of 60 per cent. steel was in use. The analysis of this iron was, approximately, carbon 3.00 to 3.20; silicon 1, manganese 0.80, sulphur 0.120 and phosphorus 0.30 per cent.; and it was used for castings

Unetched, × 100.

(4B).

SILE STRENGTH 32.9 TONS. BRINELL NO.: 285. 0.69; S, 0.08; P, 0.08; NI, 1.12; CR, 0.08 PER

requiring good wearing surfaces. The standard arbitration test-bars made from this mixture were either white or mottled and as such were not suitable for test. A thicker test-bar would have been very serviceable for this iron. A specimen cut from liners cast 1½ in. thick broke at from 16.9 to 17.8 tons tensile strength per sq. in.

Some few years ago, the germ or nuclei theory of carbon particles became fairly well established. The natural reaction of many foundrymen therefore was to reduce the number of these nuclei in the iron going into the cupola by reducing the percentage of pig-iron charged and by increasing the percentage of steel. This was first done by running a mixture of nearly all steel with just enough ferro-silicon to make it leave the cupola containing 1 per cent. silicon. By the above procedure it was thought to keep the metal free from graphite nuclei. The iron was then deoxidised and greyed in the ladle by the addition of ferro-silicon, ferro-manganese and shot nickel. The iron produced by this method is close-grained and strong.

This procedure has been modified in the author's foundry by adding most of the ferro-silicon and ferro-manganese in the cupola with only a small amount of ferro-manganese-silicon added in the ladle. The " F " ingot nickel may be added in the cupola or ladle. When added in the ladle, the nickel is preheated to a dull redness before adding to the partly-filled ladle. Personal experience shows the use of nickel shot is to be avoided, especially for large ladles.

When using molybdenum it is added to the stream of iron in the spout in the form of powdered ferro-molybdenum. The alloy used contains 60 to 70 per cent. molybdenum and is readily dissolved by the hot iron. No difficulty has been experienced with its use. The addition of nickel or molybdenum facilitates machining, increases the Brinell hardness, and adds somewhat to the tensile strength. It is personal practice to add 1 per cent. nickel or 0.35 per

cent. molybdenum. The 1 per cent. nickel, however, will have more effect on machining properties than the 0.35 per cent. molybdenum. As the cost of molybdenum per lb. is approximately three times that of nickel, the cost per ton of iron is the same regardless of which alloy is used in above proportions. By the above method, no large amount of cold material is added to the iron in the ladle. While the freedom from nuclei may not be quite so complete as when following the first described procedure, it is found there is a greater certainty of the iron being in condition to use.

In discussing the making of high-test iron by the cupola process in the United States of America, it should be remembered that almost all the cupolas are operated without a forehearth. This naturally results in tapping at intervals, between which the iron rises in the cupola to make contact with the coke. The carbon pick-up therefore is much greater, and consequently there is a greater difficulty in obtaining a low-carbon iron in the ladle than if a forehearth were used. To avoid this difficulty there has been an increasing percentage of steel added to the mixture. For this and for other reasons some American foundries are now using a tilting Y-shaped spout in front of the cupola tap hole. This spout makes it possible to run the iron down either leg or side as desired, and allows the stream of iron to be continuous, for it is not necessary to stop up the cupola. It has been reported by those using this process that mixtures with 25 per cent. steel will result in 0.15 to 0.25 per cent. lower total carbon product than when using the intermittent tapping process.

It is estimated that about 130 American foundries make an intermediate iron from charges containing about 50 to 60 per cent. steel, with a tensile strength of 16.9 to 22.3 tons per sq. in. It is likewise estimated that about 30 foundries use a mixture for high-test iron with over 80 per cent. steel, with test-bars breaking over 22.3 tons per sq. in. This estimate was reported by

Mr. F. B. Coyle, of the International Nickel Company.

It might be of interest to outline the details of one example of producing the high-steel charge

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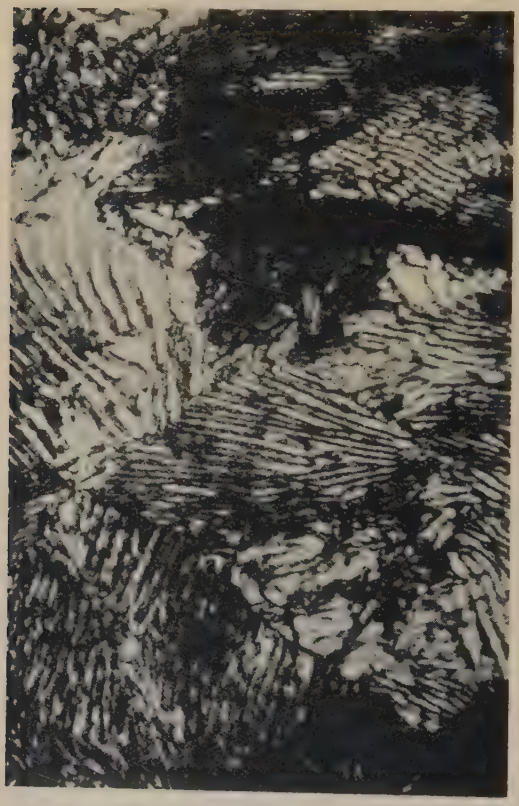

(5A).

FIGS. 5A AND 5B.—CUPOLA IRON AS CAST.—TEN COMPOSITION: T.C., 2.64; SI, 2.16; MN, AND MO, 0.34 PER CENT.

metal which has been in successful operation for over four years. The cupola is 34 in. internal diameter, carrying six tuyeres assembled as one row. The tuyeres are 19 in. long by 5 in. high,

Unetched, × 100.

(5B).

silk Strength, 31.3 tons. Brinell No., 227. 0.73; S, 0.084; P, 0.08; Ni, none; Cr, 0.06,

and are equally spaced around the cupola with the lower edge 19 in. above the sand bottom. The by-product coke used contains 8 per cent. ash and 0.7 per cent. sulphur. 2,300 pounds of this coke are used on the bed, most of which is charged on the wood. After burning through, the remainder of the coke is added, and the bed levelled off. In charging, the pig-iron and scrap are put first, the steel is then added and the ferro-silicon thrown on top of the charge. After filling the cupola, it is allowed to stand one hour before the blast is put on.

The metal charges are 1 ton 6 cwts. 3 qrs. in weight, with 3.25 cwts. of coke between charges. The charge consists of from 4 to 5 per cent. of 50 per cent. ferro-silicon, 0.5 per cent. of ferro-manganese, 6 to 10 per cent. return high-test iron scrap, 5 per cent. pig-iron, with the remainder steel. The steel is two-thirds railway wagon springs and one-third steel rails cut to 2-ft. lengths. A blast of 3,600 to 3,800 cub. ft. of air per min. is used, with a pressure of from 4 to 5 ozs. As a low carbon is desired, short taps are made, and the cupola is kept fairly free from melted iron. It would be possible to reduce the total carbon in the iron by using less coke, but in view of the importance of having hot iron, it is preferred to use the coke specified. To each 1,000 lbs. of metal going through the spout, there is added 3 lbs. of powdered ferro-manganese silicon (silicon 50 per cent., manganese 25 per cent.). When large castings are to be made with little machine work, no alloys are added. When small castings are to be made with much machine work, either 1 per cent. nickel or 0.35 per cent. molybdenum are added. Castings made from this iron include frames, tie pieces, hydraulic casings, gears, drums, dies, etc.

The iron so made has a short freezing range, and must be handled quickly. In practice it does not show a high internal shrinkage or porosity. It must be poured hot and fast and sand may burn on to the casting to some extent unless the

sand is of a good quality. Dry-sand moulds are to be preferred and large risers should be used where possible. This iron is considerably harder than the average cast iron and, in fact, machines in a similar manner to a steel casting. The structure is pearlitic, with small graphite flakes. There are, of course, possible foundry troubles when using this iron, but none that cannot be overcome.

Table I details results covering a month's run, and includes 15 consecutive routine tests, all with nickel additions being reported. In this table are listed representative tests of several ladles using molybdenum and also of several heats using no alloys. These results are not in

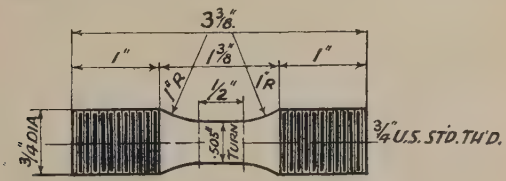

Fig. 6.—Tensile Bar Used.

any way research or experimental, but were all made on ladles of iron used to produce commercial castings. On 200 consecutive routine tests made in 1929-30 the average tensile strength was 24.9 tons per sq. in. All bars used were standard arbitration bars, $1\frac{1}{4}$ in. in diameter and broken transversely between 12-in. supports. The tensile test-pieces (Fig. 6) were cut from the broken halves of these bars.

In order to compare these tensile bars with one more nearly like the British standard bar, the following tests were made. Six arbitration bars were taken at random and broken transversely as usual. From the broken ends of each bar two tensile specimens were machined, one into the standard American tensile bar and the other into a tensile bar 0.750 in. in diameter for a clear space of 2 in. between the bottoms of fillets. The results from the latter type bar

are those marked with an asterisk in Table I. The results from the American bar are those given in the upper half of the same bracket. As the agreement between the two types of test-bars was good, the remainder of the tests were made on the former type of bar.

A variation in silicon of from 2.0 to 2.75 per cent. does not materially affect the strength. A high silicon, however, does tend slightly to soften the casting. If additional hardness or resistance to wear is desired, powdered ferro-chromium may be added in the spout. Higher strength values are obtained by using a higher percentage of alloys. The cost is increased, however, with the higher percentage of alloys and there is a limit beyond which it is not commercially practical to go. The author has not proceeded with the heat-treament of this iron as the size of his firm's castings is such as to make this inadvisable.

Castings have been made which weighed 50 tons in the rough and there is no reason to believe there need be any particular limit in size. Two cupolas 72 in. diameter were used to melt the iron for these castings. Some time ago a 25-ton casting was made and broken up for test purposes. Arbitration test-bars cast from the ladle iron broke at 22.5 tons per sq. in. Tensile bars machined from a rib $2\frac{1}{2}$ in. in thickness broke at 18.7 tons per sq. in. and tensile bars trepanned from centre of a 6-in. section in middle of casting broke at 13.3 tons per sq. in. The grain was fine and close throughout. No shrinkage or spongy spots were found where light and heavy sections came together. The analysis of this metal gave:—T.C., 2.73 per cent.; Si, 2.36; Mn, 0.73; S, 0.09; P, 0.08 per cent.; chromium, nickel and molybdenum were not incorporated in the mixture.

Miscellaneous Physical Properties.

Effect of Section.—This higher test iron shows less loss of strength in heavy sections than the other irons lower in tensile strength; also, the structure is more nearly uniform throughout,

TABLE I.—*Physical Tests from Arbitration Test-Bars detailed in Fig. 6.*

(*Iron melted in a 54-in. Cupola.*)

Date cast.	Size ladle, lbs.	Trans. load in lbs.	Def. in.	M.S. tons per sq. in.	Brinell hardness.	T.C.	Si.	Mn.	S.	Ni.	Cr.	Mo.
5/12/31 ..	7,000	5,780	0.16	26.2 25.8*	285	2.73	1.88	0.63	0.079	1.12	Tr.	None.
5/12/31 ..	2,000	5,730	0.14	32.9	285	2.64	2.14	0.69	0.080	1.12	,,	,,
5/12/31 ..	7,000	5,560	0.14	29.7	297	2.50	2.16	0.74	0.078	1.00	,,	,,
25/11/31 ..	7,000	5,600	0.15	26.3	277	2.97	1.88	0.62	0.087	1.37	,,	,,
25/11/31 ..	7,000	5,800	0.16	28.1 28.9*	285	2.87	2.05	0.64	0.091	1.20	,,	,,
25/11/31 ..	2,000	6,270	0.17	29.0	293	2.50	2.66	0.72	0.103	1.29	,,	,,
13/11/31 ..	7,000	5,850	0.17	26.8 26.9*	285	2.79	2.00	0.61	0.088	0.88	,,	,,
13/11/31 ..	7,000	5,630	0.15	24.5 24.5*	293	2.61	2.25	0.68	0.081	1.29	,,	,,
4/11/31 ..	9,000	5,740	0.15	24.5	277	2.81	2.07	0.67	0.093	1.15	,,	,,
4/11/31 ..	2,000	6,020	0.19	29.2	285	2.91	1.97	0.71	0.087	0.97	,,	,,
4/11/31 ..	9,000	5,810	0.16	27.9 27.8*	277	2.82	2.16	0.68	0.080	1.20	,,	,,
30/10/31 ..	9,000	5,390	0.18	24.3	262	3.05	2.37	0.70	0.096	1.01	,,	,,
30/10/31 ..	6,500	5,960	0.19	27.3	262	2.79	2.34	0.75	0.087	0.98	,,	,,
30/10/31 ..	25,000	5,220	0.16	23.1 23.5*	262	2.73	1.93	0.62	0.091	1.03	,,	,,
28/10/31 ..	5,000	5,330	0.15	26.5	252	3.11	1.81	0.67	0.090	0.88	,,	,,
11/12/30 ..	2,000	5,480	0.18	31.3	277	2.64	2.16	0.73	0.084	None	,,	0.34
17/2/30 ..	2,000	6,240	0.18	29.9	277	2.51	2.82	0.74	0.089	,,	,,	0.28
22/12/31 ..	2,000	6,470	0.19	27.8	262	2.74	2.41	0.74	0.072	,,	,,	0.29
				(*Iron melted in a 72-in Cupola.*)								
9/9/31 ..	20,000	4,960	0.15	24.8	265	2.59	1.88	0.80	0.089	Tr.	Tr.	None.
22/7/31 ..	44,000	5,160	0.14	22.9	255	2.94	2.65	0.77	0.100	,,	,,	,,
27/2/30 ..	20,000	5,170	0.16	27.6	285	2.60	2.07	0.70	0.100	0.19	,,	,,

although the grain becomes somewhat more open as the centre is approached. The hardness of a 4-in. section was practically uniform.[1]

Elongation is low, only 0.5 per cent. being observed in untreated bars.

Fatigue.—A plain high-test cupola iron with a tensile strength of 22.4 tons per sq. in. was tested in fatigue, using the "RR" Moore machine. The endurance limit[2] found was 10.7 tons per sq. in.

Effect of Heat.—An effort was made to determine the effect of a prolonged heating at high temperature.[3] It was hoped that the low carbon and fine grain would maintain its hardness and strength. This did not prove to be so, although the specimen containing chromium was better than the others, the major change taking place in the first 500 hrs. Specimens were held at 593 deg. C. for 8,000 hrs., the test being interrupted at long intervals to determine loss of strength and hardness.

Impact.—This iron shows a much higher impact value than the lower tensile strength irons. There is as yet, however, no standard methods of comparison.[4]

Wear.—There are many references in published literature to increase resistance to wear in using this iron, but the writer has seen no reliable data. This is a subject on which there is a great need of research. In writing the above an effort has been made to eliminate theory as far as possible and to outline only operations in commercial practice.

In conclusion, it is the author's opinion that the development of cast iron is only in its infancy. Heat-treatment and alloys will do as much for cast iron as they have done for cast

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1 R. S. MacPherran, "Effect of Section and Various Compositions on Physical Properties of Cast Iron," Proceedings A.S.T.M. (1929), Part 2, Vol. 29, pp. 76-82.

2 J. B. Kommers, "The Static and Fatigue Properties of Some Cast Irons," Proceedings A.S.T.M. (1928), Part 2, Vol. 28, pp. 174-197.

3 Apparatus described in Paper, "Effect on Cast Iron of Prolonged Heating at 800 deg. to 1100 deg. F.," by R. S. MacPherran and R. Krueger, Transactions A.F.A., Vol. 38 (1930), pp. 826-855.

4 H. Bornstein, "Impact Testing of Cast Iron," Proceedings A.S.T.M., Part 2, Vol. 29 (1929), pp. 109-114.

steel. Grateful acknowledgment is accorded to the following persons and organisations for permission to publish information concerning the material from their respective foundries:—Mr. H. E. Bromer, Standard Racine Foundry Company, Racine, Wis.; Mr. H. B. Swan, Cadillac Motor Car Company, Detroit; Mr. H. S. Austin, Campbell, Wyant & Cannon, Muskegon, Mich.; Mr. D. F. Forbes, Rockford Northwestern Malleable Corporation, Rockford, Ill.; Mr. W. J. MacNeill, Federal Malleable Iron Company, West Allis, Wis.; Mr. Oliver Smalley, Meehanite Corporation, Chattanooga, Tenn.; Mr. J. J. White, Erie Malleable Iron Company, Erie, Pa., and Mr. Wm. Watson, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

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"Electric Furnace Grey Iron," by Edwin L. Willson, Philadelphia, A.F.A. Transactions, Vol. XXXII, p. 569.

"The Electric Furnace in the Pipe Foundry," by Jas. T. MacKenzie, Birmingham, Ala. A.F.A. Transactions, Vol. XXXII, p. 565.

"Melting Grey and Malleable Iron in the Indirect-Arc Furnace," by J. C. Bennett and J. H. Vogel, York, Pa., A.F.A. Transactions, Vol. XXXIX, p. 235.

"Electric Furnace Iron from Manager's Viewpoint," by L. J. Barton, A.F.A. Transactions, Vol. XXXI, p. 148.

"Grey Iron from Point of View of the Electric Furnace," by G. K. Elliott, A.F.A. Transactions, Vol. XXXI, p. 136.

"Electric Melting of Cast Iron," by G. E. Lamb., A.F.A. Transactions, Vol. XXXIII, p. 492.

"Manufacture of Synthetic Foundry Iron in the Electric Furnace," by C. E. Sims and B. M. Larson, A.F.A. Transactions, Vol. XXXI, p. 154.

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DISCUSSION.

MR. C. H. KAIN said that the Paper was remarkably interesting as showing what immense possibilities there were in the making of high-strength irons. In general, the results and findings quoted were in agreement with his own experience in the production of quality irons, but one or two statements called for comment. The price of £6 1s. 4d. per ton of metal in ladle, given as the cost of a duplex process, was high compared with the practice in this country and must be far in excess of the cost of the cupola metal mentioned in the Paper. In nearly all cases, the silicon content was much higher and

the combined carbon lower than would be used for the same conditions in this country. One naturally expected these two features to be associated, but it was difficult to account for the high strength and Brinell hardness in irons having such low combined carbon. Superheating was mentioned as causing refinement of grain. What temperature was meant by superheating? Claims were frequently made to casting temperatures of over 1,500 deg. C. from the cupola.

This figure was at least 50 deg. C. too high, and, where it was registered, the foundry concerned would be well advised to check its pyrometry, especially if the structure of the iron showed flake graphite. Dr. Norbury and the B.C.I.R.A. had shown that superheating definitely produced a ferrite, long, dark, fine-graphite structure which was comparatively weak and soft, but which was readily machinable. It was also his experience that superheating was often associated with the phenomenon known as "inverse chill," particularly when the temperature was over 1,500 deg. C.

In the example given in detail of a cupola producing high-test iron, the charge was said to include 6 to 10 per cent. returned high-test iron scrap. As this type of iron required very heavy feeders, etc., the yield of castings was seldom more than 60 to 65 per cent. Therefore, there must be at least 35 per cent. remelt in each charge unless the scrap was sold. It would be interesting to know how this was dealt with at the plant in question. Finally, a ladle addition of ferro-silicon and ferro-manganese was made. As this addition absorbed heat, was any difficulty experienced with chilling of the metal, incomplete alloying or short-run castings? Would it not be advisable to make use of the exothermic reaction which occurred when CaSi was added to the metal at the spout?

He would like to congratulate Mr. MacPherran on his excellent Paper, and to thank him for collecting and preparing such a mass of valuable data.

Cupola Melted Irons.

Mr. F. K. Neath, B.Sc. (Keighley), said that he proposed to confine his remarks to the cupola-melted irons mentioned in Mr. MacPherran's Paper. Table I confirmed the general experience with low-carbon irons, that the silicon content did not matter very much as long as it was between 1.5 per cent. and 3 per cent. It would appear, however, that whilst high-tensile could be obtained in this way, it was difficult to say beforehand what the tensile would be, *i.e.*, 23 tons or 30 tons per sq. in. This wide variation seemed to indicate that some other variable was at work besides composition and possibly a combination of graphite size and distribution was the factor. The question was, did this variation in tensile indicate some factor which should be more fully understood, as the higher the quality of the material, the more necessary it became to have reliable data upon which to work for designing purposes? According to Mr. MacPherran, the Brinell hardness of a 4-in. section was practically uniform, whereas the tensile strength varied from 22.5 tons per sq. in. in a $1\frac{1}{4}$-in. dia. bar down to 13.3 tons per sq. in. in a 6-in. section of a casting. Would the same relations hold for metal which gave 30 tons tensile on a test-bar?

Mr. MacPherran's Paper was a valuable addition to the proceedings of the Institute, as foundrymen in this country would now have an authoritative summary of the present position of high quality irons in America. Mr. Kain's remarks regarding temperature measurement at 1,500 deg. C. raised a very pressing problem which still awaited a practical solution.

The Chairman (Mr. C. E. Williams) bringing the discussion to a close, said that he noticed that one of the tests mentioned in the Paper lasted 8,000 hours, which was roughly about eleven months. He thought that this was an extraordinary test. These international Papers had great value in helping the world to settle down because of their usefulness in distributing knowledge. They ought to

do all they possibly could to encourage international Papers.

A Survey of Testing Conditions.

Mr. J. G. Pearce, M.Sc., Director, British Cast Iron Research Association, wrote that he had an opportunity two years ago of seeing the production of high-test cast irons in the United States and saw the material made by Mr. MacPherran at the Allis-Chalmers works. The report then prepared was confirmed in practically all points by Mr. MacPherran's description, although considerable progress had evidently been made in the meantime. The results gave cause for congratulation. They pointed to the value of the procedure which the British Cast Iron Research Association calls the inoculation process, which has followed the development of the germ theory during the last few years. It is assumed that the ferro-manganese used by Mr. MacPherran is the 80 per cent. manganese alloy, and the writer would like to know the carbon contents of both this and the ferro-manganese-silicon alloy used as a ladle addition.

It was particularly interesting to notice that Mr. MacPherran's results are obtained in the soft-blast type of cupola which the British Cast Iron Research Association had consistently advocated, particularly for steel-melting, for a number of years.

Mr. MacPherran gave some figures tending to show that similar results are obtained from both British and American standard tests. It is suggested that these figures did not wholly dispose of the problem, as British founders had occasionally been puzzled by the comparatively high American figures. In the standard British specification the 0.875-in. bar was machined to 0.564 in. for tensile and the 1.2-in. bar to 0.798 in. The American standard 1.25-in. bar was machined for tensile to 0.505 in., and for hard irons it had frequently been found that this gave a higher tensile figure than the larger bar. The American bar, moreover, was cast in a dry-sand mould or cores, whereas the British

bar was cast usually in green sand. Recent experience had shown that hard irons cast in dry sand had higher strength than similar irons cast in green sand. Soft irons, however, were ameliorated by the slightly chilling effect of the green-sand mould. So far as the transverse test was concerned, a bar tested at 12-in. centres would be slightly stiffer and had a greater breaking load than would be expected by ordinary calculation from the result of the same bar tested at 18-in. centres. In other words, the load on a transverse bar tested at 12-in. centres would be greater than that on the same bar tested at 18-in. centres than was given by the ratio 18 : 12. These differences suggested that in order to see whether the American test gives consistently higher figures than the British test on the same iron, the whole of the details of the specifications of the respective countries required to be followed out, and it is suggested that interested British manufacturers might try this. Altogether Mr. MacPherran's Paper is one on which he can be very cordially congratulated.

Mr. Frank Hudson, in a written contribution, said he was particularly interested in what had been said, as it was so essentially practical and constituted such an excellent advertisement for the ironfounder. As sellers of castings to the engineering industry, the more we can convince engineers of the great improvements being made in our trade then the greater are potential sales. Accordingly he felt that British foundrymen should be deeply grateful for the able way in which Mr. MacPherran has outlined the progress made by our friends in the United States, as at the present time the comparison is particularly valuable in view of recent developments in this country, making particular reference to the work of Mr. J. E. Hurst in connection with the heat-treatment of cast iron, and with the developments at Sir W. G. Armstrong Whitworth's Close Works foundry employing pulverised-coal-fired rotary furnaces for the direct production of high-test cast iron.

The economic conditions prevalent in this country do not lead to the use of electric furnaces for the production of iron castings, and personally he did not see any future hope that their employment was likely to arise. Accordingly the latter part of Mr. MacPherran's Paper treating on the production of high-test cast iron from the cupola is most likely to be of direct interest. One was apt to be misled, however, in assuming that the use of high steel-scrap percentages in the cupola charge will effect a cost reduction in price of raw materials used. It should be remembered that if great care is not taken in properly controlling the amount of additional alloys, such as ferro-silicon, ferro-manganese and nickel, any advantage in cost will be lost. Perhaps it might be contended that the aim was not to reduce cost so much as to increase quality, but surely the true aim in all business principles was to produce the highest quality at the lowest price. It is of interest to compare the cost of the mixture used by Mr. MacPherran as given on page 3, column 3, of the Preprint against ordinary practice:—

	Per ton £ s. d.
Cost of raw materials using Mr. MacPherran's high-steel 1 per cent. nickel mix	5 1 7½
Cost of raw materials as above without nickel addition	3 0 0
Cost of average cupola mixture using, say, 50 per cent. pig, 50 per cent scrap	2 18 0

From this it will be noted that the high steel-scrap mixture is 2s. per ton dearer than an ordinary mixture composed of 50 per cent. pig. More economical results could be obtained in many foundries by adopting a 1.5 per cent. silicon mixture where casting section permits. At the present time his firm were experimenting on a mixture made up as follows:—3 per cent. ferro-silicon, ¾ per cent. ferro-manganese, 13 per cent. cast-iron scrap, and 82¼ per cent. steel

scrap. This should produce results equal to those obtainable by Mr. MacPherran, and its cost is only £2 15s. 3d. per ton, or 2s. 9d. cheaper than the ordinary mixture given above. Of all the elements affecting the successful economic cupola melting of high steel-scrap charges, it is thought manganese warrants the most attention to obtain success.

AUTHOR'S REPLY.

The author wishes to express his appreciation of the friendly tone shown in the discussion of the Paper on "High-Test Iron" which he presented on behalf of the American Foundrymen's Association to the Newcastle Conference.

Mr. Hudson is correct in assuming that the cost of the mixture in the ladle was not a primary reason for the development of this material. What was desired was a very strong, dense material, but not too difficult to machine. With regard to the use of alloys to reduce machine time, it should be pointed out that this factor becomes more important as the rate per hour paid to workman increases. For example, it might be profitable for one shop paying the men three shillings an hour to add alloys to reduce the machine time of a certain casting by one hour. The same alloy addition might not be profitable in a shop where the men were paid only one shilling per hour. Comparative costs will vary not only between different countries but between different cities in the same country and there would be still more variation from year to year. The costs given for the mixture used in the electric furnace and referred to by Mr. Kain were based on materials purchased in 1929 and 1930. The same materials purchased in 1932 would be materially lower. The pouring temperatures were, unfortunately, not a matter of record, but tests made in 1931 show a temperature of 1,500 deg. C. as coming from cupola, 1,330 deg. C. as poured into moulds. As to the amount of scrap used in mixtures, it should be pointed out that the amount produced in excess of that used in the high-test mixture was added

with advantage to our other mixtures. The small ladle addition of ferro-manganese-silicon had no visible effect on the temperature of the metal. The author's concern had no experience with the addition of calcium-silicide.

In reply to the question of Mr. Neath as to the effect of section, it can be stated that there is a greater loss of strength than of hardness as one went from the outside to the centre of the large section. In the case referred to, that of a $1\frac{1}{4}$-in. dia. bar, it was a separately-cast test-specimen, and the 6-in. section was cut from the centre of the 25-ton casting. As Mr. Neath points out, there is often a variation of strength from ladle to ladle and from day to day. These heats were not made on experimental work, and varied from day to day in amount melted and in size of ladles. In general, it was found that a high pouring temperature was favourable to high loads. This meant indirectly that a small ladle, through filling more quickly, was more apt to show a high load than a large ladle.

In reply to Mr. Pearce's question on the composition of materials used, he would say that the ferro-manganese contains 80 per cent. manganese and about 6 per cent. carbon, and that the ferro-manganese-silicon contains manganese 25 per cent. and silicon 50 per cent. The amounts used, however, were so small as not to affect materially the total carbon of the iron in the ladle.

Referring to test-bars, it should be pointed out that all fillets were easy and threads were made to fit a little loosely in the chuck. Every effort was made to have the load applied axially with no bending moment. Many American companies use a ball-and-socket holder. After machining, the surface of the test specimen is ground or polished. Bars so prepared and tested will probably average a higher load than when less care is taken. We regard these details as being legitimate when making tests of cast iron, as the tensile test has sometimes suffered from lack of such precautions.

A RÉSUMÉ OF THE WORK OF THE MALLEABLE IRON SUB-COMMITTEE OF THE TECHNICAL COMMITTEE.

Introduction.

This Paper is a record of the work of the Malleable Sub-Committee (of the Technical Committee) since its inception on October 18, 1930, to the present date (May, 1932); and is based on the various Reports presented to the parent Committee during that time.

As requested by the Technical Committee, all the available specifications were first examined. The following were collected:—

B.E.S.A. K17-18. April, 1925.

B.E.S.A. 309/10. 1927.

B.E.S.A. 143 and 154. 1922.

B.C.I.R.A. No. 22. October, 1928.

London County Council.

Admiralty. MS/3035. 1915.

A.S.T.M.

International Malleable Cast-Iron Specifications.

Air Board C.I.2.

German Specifications. Te 32.92, Te 38.92, Te 35.92, Te 38.92 D, Te 35.92 D.

French Specifications.

Railway Specifications.

A number of others were collected from individual firms, and whilst the existence of specifications issued privately by consumers or manufacturers was known, it was felt that to obtain these for publication was to ask for information of a commercial character, and this was definitely outside the scope and work of the Committee. The majority of the specifications appear to be based on the B.E.S.A. (B.S.I.) Specifications Nos. 309 and 310 of 1927, and as the Institute

of British Foundrymen was represented on the Committee compiling these specifications, it was decided that the examination of these two specifications should form the basis of the work of the Sub-Committee; having in view, if it were found necessary, an improved specification and making its provisions universally accepted and used by both manufacturers and consumers of malleable castings.

B.E.S.A. (B.S.I.) Specifications Nos. 309 and 310, 1927.

Since the examination was of a general character it was felt that both types of malleable cast iron, viz., white-heart (or Reaumur) and black-heart (or American) could be inspected together.

These specifications are dated November, 1927, and it was felt that improvements in the manufacture of malleable since that date were such that the old specifications should be thoroughly examined, and, if necessary, suggestions for a new specification drawn up. As is well known, the specifications deal particularly with mechanical tests upon a standardised size of test-bar, and allow of a wide range of chemical composition. This latitude in composition is approved of by the Sub-Committee in the light of their experience and from the results obtained upon the various specimens examined in the course of the work undertaken.

Discussion has shown the specifications to be unsatisfactory in the following matters:—

(1) The standard set is low, easily attained and often exceeded by the manufacturer. It seems, therefore, that, to make progress, this standard should be re-examined and possibly raised.

(2) A standard-sized test-bar is called for, and this cannot always represent various sizes of castings. It is quite definite in the manufacture of white-heart malleable that castings of different thicknesses must be annealed under different conditions, and therefore test-bars of a standard thickness, annealed with these different-sized castings, cannot give a true indication of the annealing of the batch they represent.

(3) The provision of three round and three flat bars for every batch of castings is irksome to the manufacturer, particularly when the quantity of castings ordered is small.

(4) The inspector must rely on the integrity of the manufacturer as to whether the test-bars are cast at the same time as the castings and annealed with them.

(5) The specification is not designed to cover castings suitable for electrical or magnetic induction purposes.

(6) The specification does not distinguish between castings for high- or low-grade work. In many cases, such as ironmongery, castings of lower specification, and hence cheaper material, would be suitable, whilst castings upon which life depends, such as automobile work, require a different specification.

Many of these objections can be overcome. One suggestion which has been put forward by the B.C.I.R.A.[1] is to use a different-sized test-bar to represent various castings. The Association suggests the use of three sizes of test-bar, viz., 0.253-in., 0.564-in. and 0.977-in. dia. The two smallest to be used for white-heart and thin-walled castings, and the two largest to be used for black-heart and thick-walled castings. The smaller size has also been advocated by Stotz[2] and by Rémy.[3]

The use of a standard-sized test-bar with varying requirements might also be considered. Thus it might be possible to use the standard 0.564-in. dia. bar with a higher specified ductility when used with thick castings requiring very thorough annealing, and a lower ductility (and possibly higher strength) when used with thin, small castings requiring less annealing.

But mechanical testing alone cannot overcome all these difficulties, and a suitable microscopical examination, either in conjunction with the B.E.S.A. (B.S.I.) specification or alone, could possibly be evolved to give satisfaction in all cases, and this should be given serious consideration.

It was therefore decided to discuss the following points in an effort to reach finality:—

(1) The use of varied-sized test-bars to suit the type of casting.

(2) The use of a standard-sized test-bar in conjunction with varied requirements to suit the type of casting.

(3) The possibility of having more than one standard grade of malleable.

(4) The effect of and the inclusion in the specification of a repeated impact test.

(5) The creation of a specification covering a test for castings for electrical work where properties such as magnetic permeability are of greater importance than tensile strength.

(6) The inclusion in the specification of a clause covering the after-treatment of malleable, such as welding, brazing or galvanising. This particularly to be a guide to the buyer as to what he may expect from malleable cast iron.

(7) The creation of a microscopical specification and its application:—(*a*) In conjunction with standard mechanical tests; (*b*) as an acceptance test; and (*c*) as a means of investigating service-failures in cases where the original mechanical test results were satisfactory.

Use of Varied-Sized Test-Bars with Standard Requirements.

In the B.C.I.R.A. Paper already referred to, Dr. Norbury shows that, with the exception of the transverse test, the mechanical tests on malleable decrease as the size of the section increases, and the Sub-Committee is confident that the suggestion of using varied-sized bars to represent varied-sized castings is a step in the right direction. Due consideration, however, will show some problems in the way of its successful adoption. The founder handling a wide range of sizes will be embarrassed by a number of different patterns, and difficulty will certainly be encountered in ensuring that the correct size of bar is cast each time. Also, the effect of small surface faults, etc., on the smaller-sized bars is magnified unduly, and in the case of larger bars

unsoundness is frequently encountered owing to gating and feeding difficulties in large elongated section.

The Sub-Committee cannot agree to the generalisation, as set forth in the B.C.I.R.A. Paper, that light castings are usually white-heart, and heavy castings black-heart, and, therefore, that the smaller test-bars be used for white-heart, with the larger ones for black-heart. Large outputs of heavy-sectioned white-heart are known, and also black-heart less than one-eighth of an inch in thickness. Therefore, it is felt that the same range of test-bars should be used for both types of malleable.

Other problems also suggest themselves, such as the decision as to the size of bar to be cast, the position of the bar for annealing, whether more than one bar shall be cast in the case of widely varying sections, and, if so, how far the results on one shall affect the interpretation of the others.

These recommendations are definitely progressive, and the sub-committee feel that by first investigating the correlation of microstructure with strength they will be furthering the work and collecting information which should be useful in compiling final recommendations.

Use of Standard Size Test-Bar with Varying Requirements.

As previously mentioned, an alternative to the above in the shape of a standard bar with modified requirements is well worthy of consideration. A single size of bar will cause little trouble in the foundry. There is no danger of pouring the wrong mould, the size can be selected so as to minimise the effect of surface imperfections, and, in any case, the effect of these is unified. The gating and feeding could be studied to ensure a perfectly sound casting and the method standardised.

The actual position of the test-bar in the annealing box would be of slight consequence since the test could easily be interpreted for each thickness of section. As already stated,

a higher test would be specified in the case of heavy castings requiring very thorough treatment, and a lower test in the case of small, easily annealed parts.

The selection of the actual test to be called for on any particular batch would present no difficulty after some preliminary experimental work had been done. This is quickly seen from Fig. 1, taken from a private communication from Mr. Pearce.[5] The curve shows the decrease in the strength and elongation of black-heart with increasing thickness of section. From this curve the inspector or buyer can readily see the

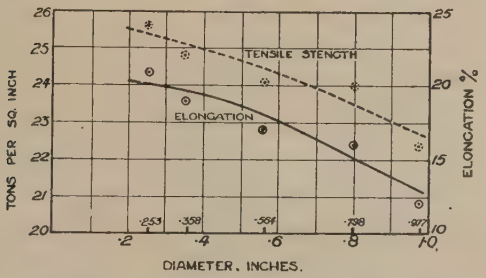

FIG. 1.—BLACK-HEART MALLEABLE CAST IRON TENSILE STRENGTH AND ELONGATION PLOTTED AGAINST DIAMETER OF BAR. TESTS MADE IN "AS-CAST" CONDITION.

strength of the various sections under consideration and call for tests accordingly. Thus, if the castings were not of the highest quality and only required for low-service conditions, the inspector could accept on a $\frac{1}{2}$-in. bar any figures falling within the range from, say, $\frac{1}{4}$ in. to $\frac{7}{8}$ in. But if the castings are required for high-service work, such as automobile parts, the test could be specified within narrow limits to ensure the maximum possible strength in the weakest part of the design. This feature should appeal particularly to designers.

It would be necessary to prepare a number of charts or curves similar to Fig. 1 for the various

materials, and possibly firms would desire to work to their own chart. This work would be of the simplest and cheapest character, and the system could be adopted very readily. The Sub-Committee intend to investigate this matter more fully as soon as the other portions have been fully considered.

Varied Grades of Malleable.

Due consideration immediately shows the futility of working to the same specification for castings to be used under widely varying conditions. It is obviously wasteful to make door knockers and buckles to the same specification as aircraft and automobile parts. Therefore, it is decided that recommendations should be made in respect of the following castings:—Agricultural castings; aircraft; automobile castings; colliery work; electrical work; engines; general ironmongery; lifts, cranes, conveyors, etc.; machine tools, textile machinery; railways and shipbuilding.

This, however, cannot be done until the present preliminary examination is finished, and the testing conditions standardised.

Impact Testing.

The resistance of malleable to shock stresses has been discussed from time to time, but the Sub-Committee is not aware of any conclusive data on the subject. For example, opinion has been expressed that black-heart ought to be exceptionally resistant to repeated impact, and therefore is especially suitable for such parts as couplings, but whether or not this is based on experimental evidence is not known. The theory advanced is that the free graphite in the form of nodular or temper carbon acts as a number of minute cushions and absorbs the shatter force of the shock.

Very little other information is available and the Sub-Committee feels that a series of tests should be made to throw more light on this very interesting subject. Owing to the necessity of

preparing special test-bars and arranging for the tests to be made, the matter was, however, temporarily shelved until the microstructures were investigated. Also, since malleable is not a homogeneous material, and in addition to the many constituents present, may vary in the size of these constituents and in the actual grain-size, it was considered that a full knowledge of the effect of the microstructure on the tensile strength, etc., would be very helpful in interpreting the results obtained. Obviously the arrangement of the various micro-constituents must have a very marked effect on the resistance to the very involved stresses set up by shock, whether repeated or otherwise. The Sub-Committee, therefore, feel justified in first investigating the microstructure.

Electro-Magnetic Properties.

The electro-magnetic properties of malleable cast iron have not received the attention they deserve. Published information is restricted to a few sources only, notably H. A. Schwartz,[4] Evans and Peace[5] on black-heart and H. Field[6] on white-heart. This information shows that malleable possesses very high permeability and exceptionally low hysteresis loss. Induction and permeability curves are shown in Fig. 2. The curves for malleable are compared here with an ordinary soft cast iron and with a special high permeability magnet-steel casting. It will be seen that the maximum permeability of both white-heart and black-heart is superior to the special steel. Hysteresis loops are shown in Fig. 3. The small area of the loop for malleable shows the least amount of energy lost in alternately magnetising.

These properties are of considerable value to the electrical industry, and in general where high permeability is required, strength is of lesser importance. It is felt, therefore, that there is need for a specification for malleable for electrical purposes. It is interesting to observe that in Germany there are specifications for

malleable covering magnetic induction and permeability.[1] The Sub-Committee intends to continue work which shall ultimately lead to the creation of such a specification in this country and hopes to obtain the support of the electrical manufacturers.

After Treatment of Malleable.

Considerable ignorance exists amongst buyers and users of malleable as to the processes or treatment which may be used on the annealed material without impairing the properties.

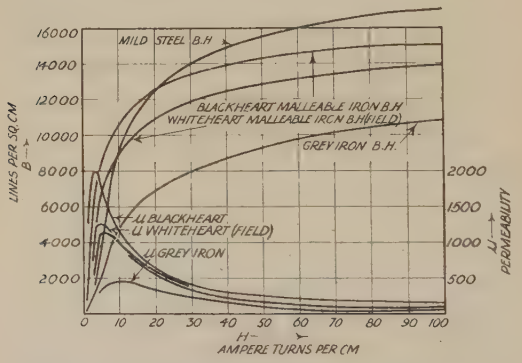

FIG. 2.—MAGNETIC INDUCTION AND PERMEABILITY CURVES OF MALLEABLE IRON, STEEL AND GREY-IRON CASTINGS.

Most of the treatments, such as brazing, welding, galvanising (and in some cases grinding or polishing) entail the use or generation of heat. The degree of this heating, together with the original structure of the casting, determines whether the process can be used with safety or not.

Correctly-made black-heart consists substantially of the stable constituents, ferrite and graphite (temper carbon), whilst white-heart, in addition to these two constituents, contains considerable amounts of metastable constituents,

such as pearlite and cementite. Heating above the lower critical point will cause re-solution of the graphite and carbides, and if the rate of cooling is similar to that of the original annealing cycle, the resultant structure will be similar to the normally-annealed material. Faster cooling will leave greater quantities of the metastable transition constituents, such as the various forms of pearlite, free cementite, troostite, etc. There is also a time lag in the

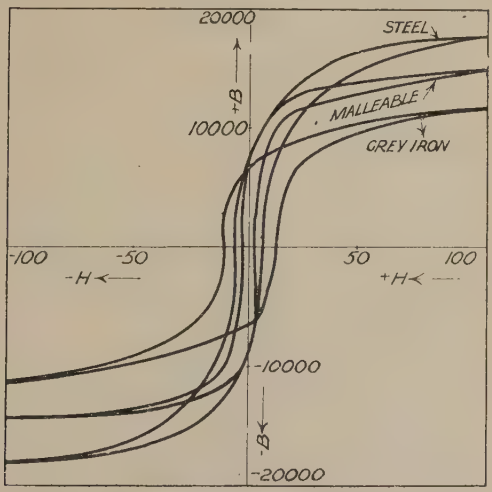

FIG. 3.—HYSTERESIS LOOPS OF STEEL, MALLEABLE AND GREY-IRON CASTINGS.

rate of solution, and the structure will be modified in accordance with the duration of heating. Obviously, therefore, if heating is taken above the critical point, unless the cooling is retarded as in the annealing process, the effect of all reheating is to convert the malleable into a material similar to the higher-carbon steels, *i.e.*, to confer greater strength with lower ductility. Useful work could be done in tabulating the temperatures used in the various processes and their effect on the properties of malleable.[8]

Some work has recently been published by Riggan[9] on the forging of black-heart malleable. He shows that greatly increased strengths may be obtained, though this is accompanied by lower elongation. Figures are given showing an increase in tensile strength from 21.8 tons per sq. in. to 46.8 tons per sq. in., with a drop in elongation on 2 in. from 11 to 3 per cent. Riggan suggests that this process might be useful in producing a casting requiring greater strength in one part to another.

Setting Malleable Castings.

Malleable castings frequently require "setting" or "straightening" after annealing before they are acceptable to the customer. This operation varies widely in different works, some reheat the castings and perform the deforming operation whilst hot, others reheat and cool slowly *after* bending, whilst others do not reheat at all. It has been contended that if the casting is "normalised" (*i.e.*, heated to 900-950 deg. C. and cooled in air) before setting, considerable deformation can be performed with safety. This theory is based on the assumption that white-heart consists largely of the steely constituents such as pearlite and cementite. But any deformation is bound to cause considerable residual stresses irrespective of the previous thermal history of the metal. Also, if any quantity of the metastable constituents are present, reheating followed by comparatively rapid cooling must largely negative the effects of the slow cooling after the original anneal. Obviously, therefore, here is a fruitful field for investigation, but consideration will show that a full knowledge of the microstructure of the various strengths would be of inestimable benefit where decisions must be made, and the only properties known are the usual mechanical ones.

Like many other ferrous materials, malleable irons suffer from a tendency to inter-granular brittleness when cooled fairly rapidly from a "blue heat," say 450 deg. C. The mechanism of this process is not fully understood, but is thought to be related to composition.[8]

It is, therefore, obvious that the properties of malleable may be very materially modified by after-treatment, and this should be brought to the notice of users. This is also an argument in favour of the use of micro-examination, since the micro-structure would be a more valuable guide to the behaviour of the material under heat than the mechanical properties. Therefore, the Sub-Committee feels justified in not publishing any data until it is in a position to cor-

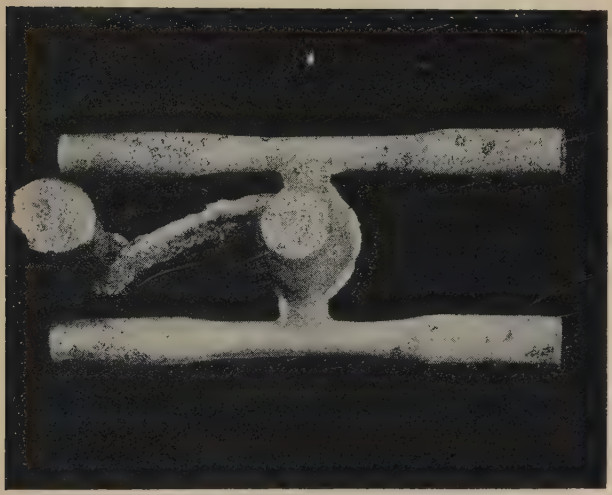

Fig. 4.—Poor Type of Test-Bar.

relate results with microstructure, since it is probable that they will then be able to show the relationship between mechanical properties, microstructure and behaviour under heat in a manner most helpful to the manufacturer in making his recommendations, and the user in stating his requirements.

Machining of Test-Bars.

During the preliminary discussions on the work to be undertaken in connection with the

correlation of strength and microstructure, it was pointed out that nearly all the published data, researches and results of investigations on malleable are based on test-bars tested in the as-cast form. That is, no metal has been removed from the surface of the bar. This is a result of two factors, first, the generally-accepted but erroneous theory that the main strength of all malleable lies in the skin (after annealing), and, secondly, the fact that it has only recently become possible to machine white-iron test-bars (before annealing) economically. The results given are frequently affected by moulding defects such as slight variations in size, roughness of surface or pock marks, cross-joints, etc., and it was decided to make a series of experiments to ascertain the desirability, or otherwise, of machining the test bars *before* annealing. Much work has already been published on the effects of machining *after* annealing, particularly in the case of black-heart.[10] Members of the Sub-Committee have also investigated this privately.

Test-bars were cast to the following sizes:—

Series A.—Tested as-cast at 0.564 in. dia. (B.E.S.A. Specification).

Series B.—Cast $\frac{1}{16}$ in. oversize and machined to 0.564 in. dia. *before* annealing.

Series C.—Cast $\frac{3}{16}$ in. oversize and machined to 0.564 in. dia. *before* annealing.

Series D.—Cast $\frac{3}{16}$ in. oversize and machined to 0.564 in. dia. *after* annealing.

The work was simultaneously carried out in five different foundries and the results are given in Table I. Foundries 1 and 2 are working on black-heart material and Foundries 3, 4 and 5 on white-heart.

The results point to the following conclusions:—

(1) The machining of test-bars *after* annealing is detrimental in the case of white-heart, but has little effect in the case of black-heart. This is in agreement with results obtained by previous workers.

TABLE I.—*Properties of Malleable C.I. Test-Pieces in the As-Cast and Machined Conditions.*

Series.	A.		B.		C.		D.	
Bar No.	Tons per sq. in.	Elong. on 2 in.	Tons per sq. in.	Elong. on 2 in.	Tons per sq. in.	Elong. on 2 in.	Tons per sq. in.	Elong. on 2 in.
				No. 1	Foundry.			
1	25.20	15.0	25.28	16.0	No	Test.	24.74	15.0
2	25.00	15.0	24.62	14.5	,,	,,	24.18	16.0
3	24.86	14.0	25.10	15.5	,,	,,	24.02	14.0
				No. 2	Foundry.			
1	25.92	14.0	26.80	16.0	26.40	17.0	24.84	14.0
2	26.64	16.0	26.08	18.0	23.84	14.0	22.40	18.0
3	24.56	15.0	25.32	15.0	24.00	13.0	20.2	9.0
				No. 3	Foundry.			
1	31.20	6.0	32.15	4.5	27.75	3.0	35.28	2.5
2	28.36	3.5	29.72	4.5	26.84	3.0	34.24	2.0
3	31.10	4.0	30.14	4.5	26.85	3.0	33.20	2.5
				No. 4	Foundry.			
1	27.10	7.0	26.04	8.0	26.10	7.0	23.20	6.0
2	26.85	6.0	25.20	8.5	27.02	6.5	25.06	5.5
3	28.36	5.5	25.92	8.5	26.54	7.0	24.52	5.0
				No. 5	Foundry.			
1	22.22	5.0	20.40	5.0	18.10	4.5	22.40	3.0
2	21.59	5.5	19.32	5.0	19.20	4.5	22.44	2.0
3	22.29	4.5	19.44	5.0	17.44	4.0	23.36	3.0

(2) The results of Series B and C tend to show more uniformity than Series A, particularly for the elongation figures.

(3) The elongation results on Series C are somewhat lower than Series B. Probably due to insufficient feeding of the larger bar, or to the increased grain size.

(4) The advantage of "machined before annealed" bars is only slight, and does not

FIG. 5.—THIS TYPE IS LIABLE TO COLD LAPS.

warrant the extra expense of machining for general tests.

It is, however, agreed that for accurate research investigation, machining of cast-bars to remove surface imperfections and to obtain correct-sized bars is an advantage, and that such machining has no effect on the mechanism of the subsequent annealing process.

These results, however, form a basis for arguments on different sized bars being used. It will be noted that the results from different foundries

vary considerably. This variation is dependent upon the annealing conditions of time and temperature. In each case the process of annealing has been controlled to give good castings, and as the size of work has varied considerably from one foundry to another, the test-bars being of constant size show widely different results. The test-bars obtained from the foundry producing light-sectioned castings are somewhat under-

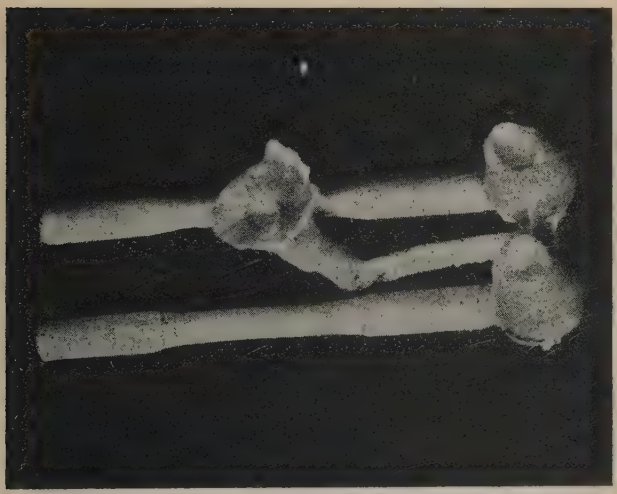

FIG. 6 IS A TYPE LIABLE TO EXHIBIT SHRINKAGE.

annealed, giving low elongation figures, whilst the bars annealed by the foundry producing heavy-sectioned castings are well-annealed, giving much higher elongation results.

In each case, however, the work annealed together with the test-bars was quite satisfactory, and would probably have given uniform results if a satisfactory method of cutting test-bars from actual castings was possible.

These results show that the present single-sized test-bar with standard requirements is not satis-

factory. Discussion on this showed the advantage of a microscopic examination being taken in conjunction with mechanical tests and also that the points raised in the introduction are mainly governed by the microstructure. It was, therefore, decided no immediate further work should be undertaken on the mechanical testing of malleable unless a request be put forward either from the manufacturers, buyers or other

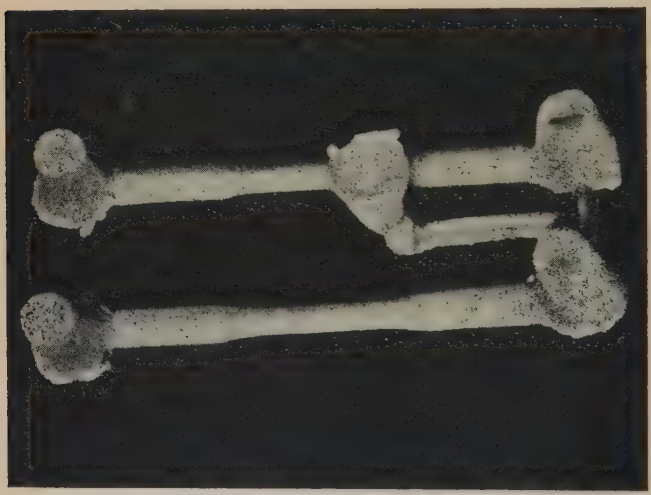

FIG. 7.—THIS METHOD GIVES SOUND BARS.

bodies, in which case the results and discussions already carried out would be available, but that the immediate future work of the Sub-Committee should be a full microscopical investigation of various types of malleable with a view to correlating the microstructure with the mechanical properties.

On the completion of the above work, the Sub-Committee was very gratified to learn that, as a direct result of the research, one very prominent malleable manufacturer connected with the

Committee and the Industry of British Foundrymen was carrying out researches, using test-bars machined before annealing.

Microscopical Examination, Specification and Correlation with Mechanical Properties.

It has not been possible to bring this important section of the work to completion owing to the large number of preliminary problems which arise. But the following notes will show how each of these questions has been overcome and

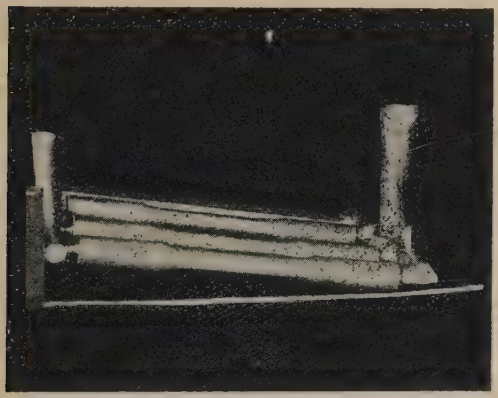

FIG. 8.—THIS METHOD IS ALSO SATISFACTORY.

the ground cleared for a full investigation. (It is necessary to add that the majority of this preliminary work was carried out on white-heart.)

The inclusion in any recommended specification of a test or tests which will tend to make that specification more universally applicable (and adopted) must be considered. The works metallurgist not only in the malleable foundry, but also in the steel, grey-iron and non-ferrous foundries, is daily using the microscope more and more to control the product under his care. Samples for microscopic examination can be

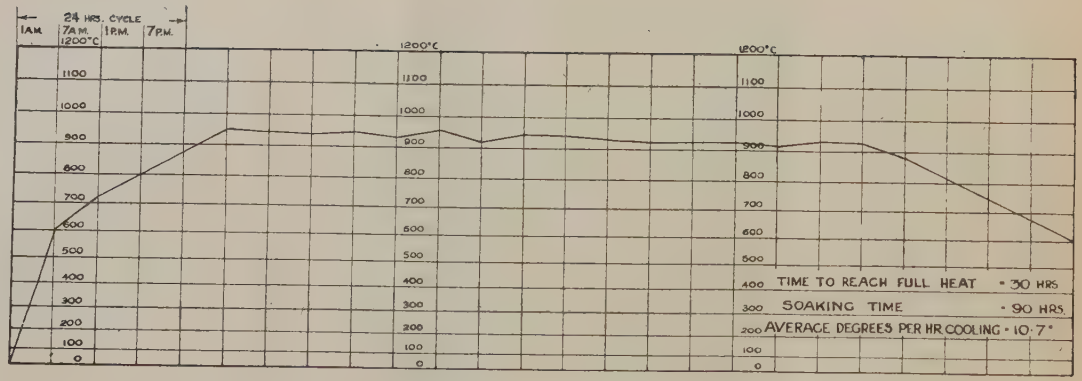

FIG. 9.—ANNEALING CYCLE USED FOR EXPERIMENTS.

quickly prepared and may be taken from any test-piece or casting to suit the requirements of the inspection. The necessary equipment for a simple examination is comparatively cheap, requiring very small space and no site preparation, and the upkeep cost is negligible.

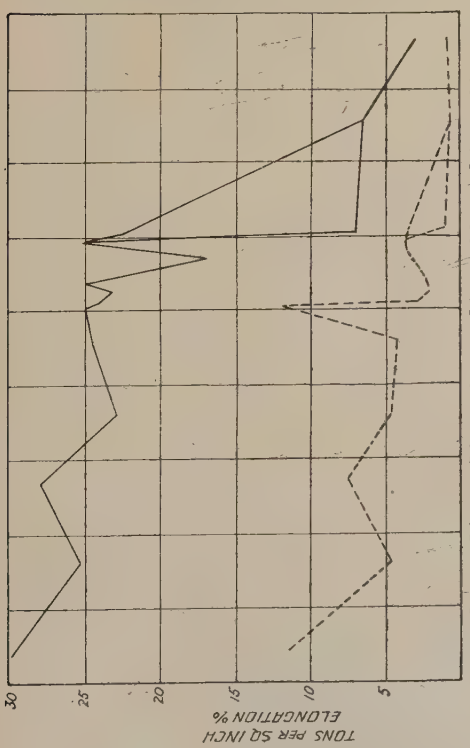

FIG. 10.—ELONGATION AND STRENGTH PLOTTED AGAINST SUMMATION OF T.C. + SI.

It was therefore considered desirable that experimental work should be undertaken to show the relationship between microstructure and other properties. As shown above, the British Standard Malleable Specification stresses more particularly the mechanical tests, this, no doubt,

being to meet the requirements of the engineers who are in the majority in buying to specification. This being so, the desirability of expressing any new test in terms of the present generally-accepted test is apparent. The correlation of mechanical strength with the micro-

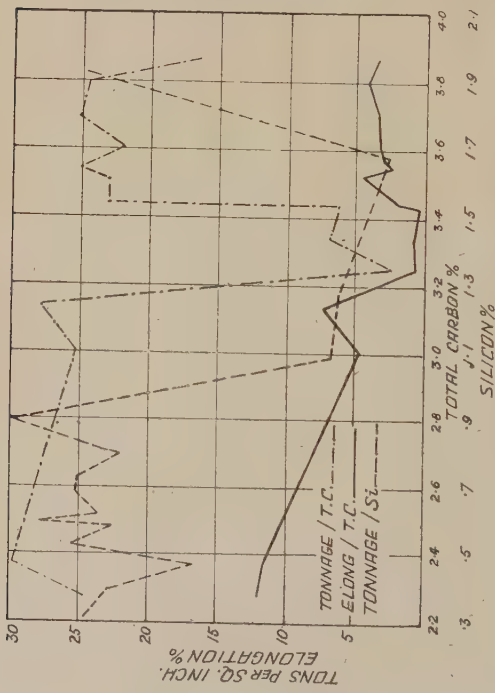

Fig. 11 shows Elongation and Strength against T.C. + Si.

structure therefore formed the first work of the Sub-Committee in this section.

Collection and Preparation of Test-Bars.

The necessary differences in mechanical strength required for comparison can be produced in two main ways. Firstly, by using a number of test-bars of one standard composition and subjecting them to different conditions of time

and temperature in the annealing process. Secondly, by using bars of different chemical composition and annealing them under the same conditions.

It was decided to use the second method, as the required conditions are more easily produced in the foundry without interfering with the works routine. The test-bars were obtained by

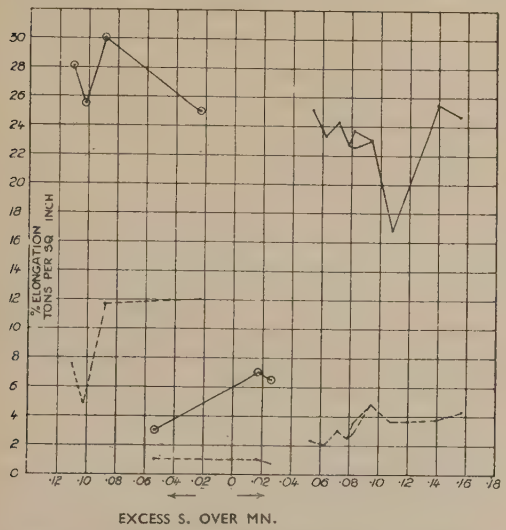

FIG. 12.—TENSILE AND ELONGATION PLOTTED AGAINST EXCESS SULPHUR OVER MANGANESE.

admixture to a normal malleable analysis, and, also, by asking malleable-iron manufacturers, to supply bars in their standard analysis, as it is well known that each manufacturer uses a different composition of iron and adjusts the annealing conditions to suit each particular analysis.

Thirty malleable manufacturers were asked to supply test-bars and the Sub-Committee was encouraged by the response to this request, many of the firms being particularly interested in the

work undertaken and sending test-bars for examination. Three test-bars to the B.E.S.A. Specification dimensions and of the same chemical composition were prepared for each series. Although previous work had shown the advisability of machining "as-cast" oversized test-bars down to the specification dimensions, it was decided to carry out the tests on "as-cast" bars, so obviating the necessity of each manufacturer preparing special patterns until the methods of preparation of test-bars, here

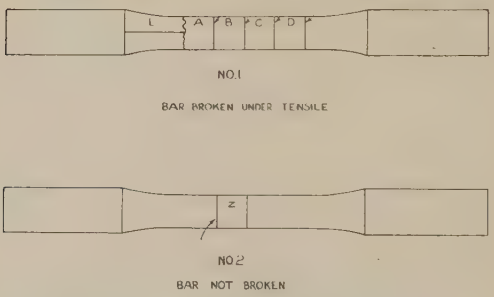

FIG. 13.—SHOWING POSITIONS USED FOR TAKING SPECIMENS.

suggested, had been available for discussion, and possibly universally recommended.

Gating and Feeding Test-Bars.

Examination of the test-bars as received shows surface faults, while many were cross-jointed and not symmetrical, and showed the widely-different methods of the makers in gating and feeding the bars. The various methods used are illustrated in Figs. 4 to 8. Providing the bars are perfectly sound any method can be used, but Fig. 4 is to be condemned, as running about the centre means subsequent treatment at the part of the bar where failure results under test. When the method shown in Fig. 5 is used, there is always the danger of surface imperfection and cold laps between the gauge lengths,

caused by the meeting of the two streams of metal. Bars cast as in Fig. 6 are liable to show shrinkage at the change in diameter away from the feeder. Feeding at each end and flowing the metal through as shown in Fig. 7 gives sound

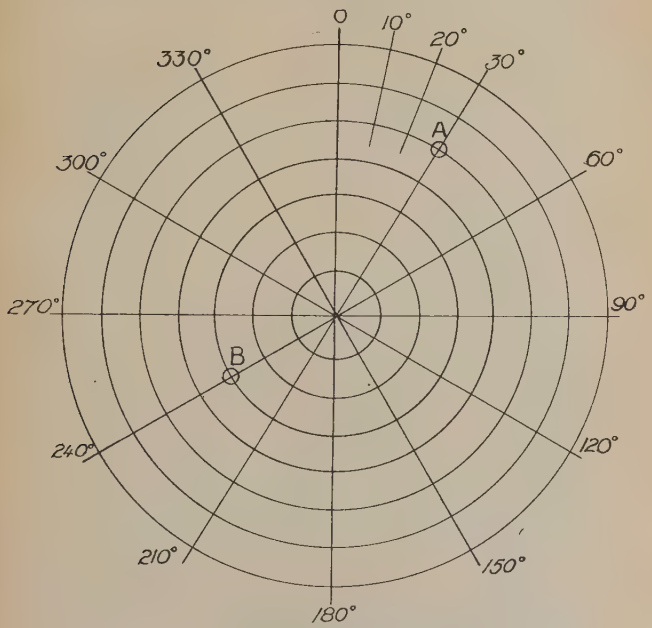

FIG. 14.—METHOD ADVOCATED FOR ESTABLISHING POSITION. FIVE TIMES FULL SIZE.

bars, as does the method of running up-hill as shown in Fig. 8. The two last-named methods or a combination of the two are recommended.

Annealing Conditions.

Each series of bars was given an identification number, turnings were taken for analysis, and then the annealing carried out. The bars were packed in a mixture of used hematite ore

to which 8 per cent. of new ore of the following analysis had been added:—

Analysis of Annealing Ore.

	Per Cent.
Ferric oxide, Fe_2O_3	79.50
Ferrous oxide, FeO	4.89
Silica, SiO_2	10.71
Alumina, Al_2O_3	Trace.
Lime, CaO	1.50
Magnesia, MgO	0.60
Manganese oxide, MnO	0.030
Phosphoric acid, P_2O_5	0.019
Sulphur	0.003
Loss on ignition	2.90
Moisture	1.0
Total iron	59.20

The packed box was placed into the oven and subjected to the annealing cycle shown in Fig. 9. The packing medium employed and the time and temperature of the anneal is generally as used for the white-heart process of malleable production, but the maximum temperature and the period at maximum temperature is somewhat lower than that usually attained in the industrial production of the majority of white-heart castings. These conditions were considered desirable, as they would tend to under-anneal the specimens, so producing greater variations in the results and allowing the mechanism of annealing to be better studied than if the bars had been fully or over-annealed.

Correlation of Strength, etc., with Composition.

After annealing the bars were tested mechanically, the results together with the analysis being shown in Table II. The consideration of the analyses show that the samples can be divided into three groups. Lab. Nos. 6,241, 6,242 and 6,262 show free graphite in the " as-cast " condition, and can be excluded from the general group, although they may be of value for very thin castings of a lower grade, and would probably only require a very short anneal.

Lab. Nos. 6,298, 6,300 and 6,302 are of black-heart composition, and should not be classed with the remaining main group of white-heart specimens. It was decided to continue the work on these eleven series of white-heart test-bars.

Fig. 10 shows the elongation and strength plotted against the mean value of T.C. plus Si in each set of bars, and Fig. 11 the strength against T.C. and against Si, and the elongation

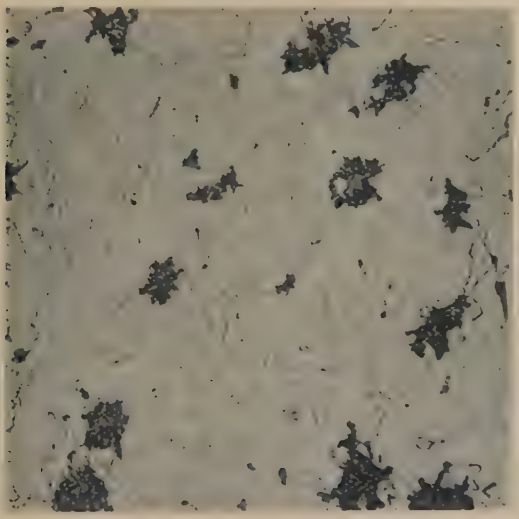

Fig. 15.—Nitric Acid. × 100.

against T.C., each point representing the mean value of each set. These curves illustrate the very involved relationship resulting from the causes already mentioned.

In addition to the examination of T.C. and Si and T.C. plus Si, the ratio of Mn and S has been studied. The tensile strengths and elongations are plotted in Fig. 12 against the excess of S over that required to form Mn S. It will be seen that in plotting all the points have not

TABLE II.—*Correlation of Composition and Mechanical Strength.*

Chemical Analysis.						Mechanical Strength.			Remarks.
Lab. No.	T.C.	C.C.	Si.	Mn.	S.	P.	Y.P.	B.	E.	
							Tons per sq. in.	M.S. tons per sq. in.	Per cent. on 2 in.	
6,240	3.44	3.04	0.81	0.16	0.154	0.25	17.0	17.0	1.5	
							12.82	24.54	2.5	
							20.98	25.05	2.0	
6,241	3.32	1.49	1.09	0.20	0.132	0.44	4.53	4.53	1.0	
							9.12	9.12	1.0	
6,242	3.25	1.34	1.68	0.23	0.078	0.85	4.17	4.17	1.0	
							1.82	1.82	1.0	
							1.98	1.98	0.5	
6,261	3.55	3.55	0.73	0.18	0.157	0.20	20.92	25.71	2.0	
							21.56	23.90	1.75	
							17.65	25.83	3.0	
6,262	3.43	1.82	1.28	0.17	0.123	0.48	5.12	6.00	0.5	
							4.94	6.36	0.5	
							6.62	6.62	0.75	
6,286	3.45	3.45	0.62	0.14	0.163	0.063	17.80	21.59	2.0	
							19.61	25.36	3.0	
							17.08	24.20	3.5	
6,290	3.42	3.42	0.59	0.16	0.170	0.059	18.14	22.30	2.5	
							18.46	23.54	2.5	
							16.80	22.00	2.5	

6,297	3.70	3.70	0.69	0.15	0.226	0.053	17.04	24.04	3.0	Run side of each end.
							16.13	26.89	4.0	
							17.04	27.27	4.0	
6,298	2.28	2.28	1.93	0.09	0.028	0.069	18.58	24.90	9.0	
							18.56	25.18	13.0	
							19.06	24.82	14.0	
6,299	3.52	3.52	0.40	0.13	0.169	0.080	16.1	23.81	5.0	Run in middle of bar.
							15.39	23.81	5.0	
							15.55	21.65	4.0	
6,300	3.14	3.14	0.60	0.31	0.066	0.027	16.14	28.57	7.5	
							15.44	27.72	7.0	
							19.69	28.18	8.0	
6,301	3.61	3.61	0.80	0.21	0.202	0.058	17.47	20.44	2.5	Run side of each end.
							18.21	22.30	4.0	
							16.91	23.86	4.0	
6,302	2.38	2.38	0.90	0.27	0.052	0.082	17.35	30.92	12.5	
							15.71	28.43	11.5	
							16.96	30.56	11.0	
6,303	3.80	3.80	0.32	0.08	0.201	0.068	16.09	23.67	4.0	Run in centre.
							15.15	25.30	4.0	
							15.61	25.09	5.0	
6,304	2.99	2.99	0.53	0.25	0.131	0.060	17.06	27.21	5.0	Run at one end.
							16.74	26.55	5.0	
							18.49	22.63	4.5	
6,305	3.87	3.87	0.48	0.14	0.189	0.049	16.70	20.69	4.0	
							12.82	12.82	2.5	
							16.39	16.39	4.0	
6,310	3.57	3.57	0.65	0.17	0.169	0.018	16.74	26.50	3.0	
							16.21	23.36	3.0	
							16.08	22.89	3.0	

been connected. The lowest figures for tensile strength and for elongation (three sets) are from test-bars which contained considerable amounts of primary graphite and are not commercial products. The other test-bars containing no excess of S are black-heart or bastard black-heart, and the points for these have not

FIG. 16 SHOWS THE SAME FIELD OF A BLACK-HEART SPECIMEN AS FIG. 15, AND ILLUSTRATES THE DIFFERENCE OBTAINED WITH DIFFERENT ETCHING MEDIA. PICRIC ACID. × 100.

been connected to the others. Looking at the graphs to the right of the figure, *i.e.*, the true white-heart malleable, it will be seen that there is no relation apparent between tensile strength and the Mn-S ratio. The results here are obscured by the very variable T.C. and Si contents. This latter variation has, however, not

prevented a definite increase in elongation being apparent with increasing excess of S. This accords with the work of Taylor.[11]

Microsopic Examination.

Distortion.

The micro-specimens for examination must not be cut from the bar in a position where the structure would be affected by any distortion

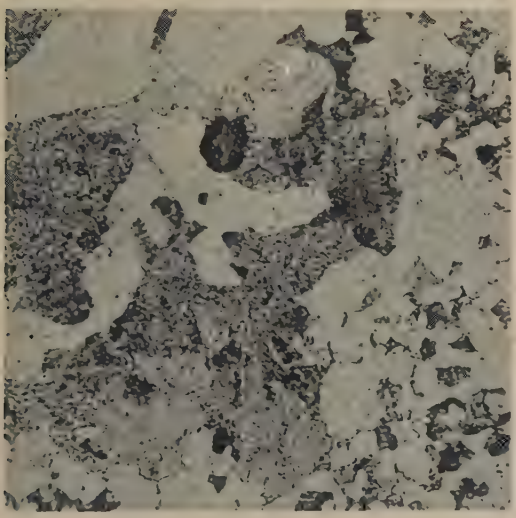

Fig. 17.—Nitric Acid. × 100.

taking place during the tensile pull. To examine the extent of any such distortion, the following experiments were carried out:—Six bars were cast of the same composition and annealed under the same conditions. Three were then pulled under tensile, the others not being tested. Micro-specimens, L, A, B, C, D and Z were cut from the bars in the position as shown on Fig. 13, the specimens being prepared

and examined on the surface indicated by the arrow. In the case of the longitudinal sample, indications of distortion were noticeable close to the fracture, but in all the cross-sectional samples, no distortion of the structure could be seen. It was therefore decided that if a micro-specimen be prepared $\frac{1}{2}$ in. away from the frac-

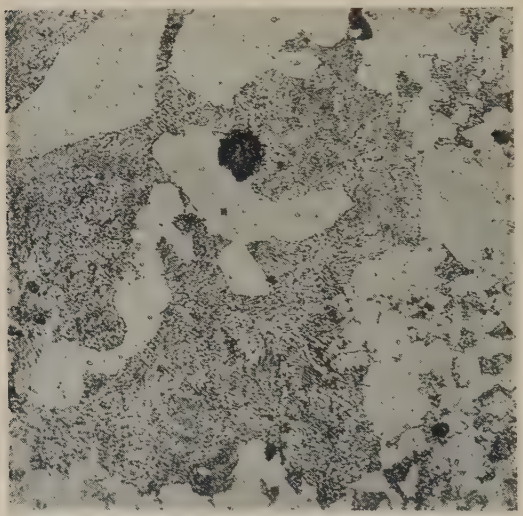

FIG. 18 SHOWS THE EFFECT OF ETCHING WITH A DIFFERENT MEDIUM FROM FIG. 17, ON A WHITE-HEART SPECIMEN. PICRIC ACID. × 100.

ture, no distortion from a direct tensile pull will be noticeable.

This method of selecting the specimens was standardised for the examination of the bars, but, of course, only applies to white-heart malleable. During the carrying out of the above experimental work, it was noticed that each member of the Sub-Committee used different methods of etching the specimens and different

magnifications for examination. So that the work of each investigator would be more easily comparable, the following standard methods of etching and examination were agreed upon and are recommended.

Etching.

When the microscopical work was projected it was quickly realised that there was no agreed opinion upon the most suitable etching reagent.

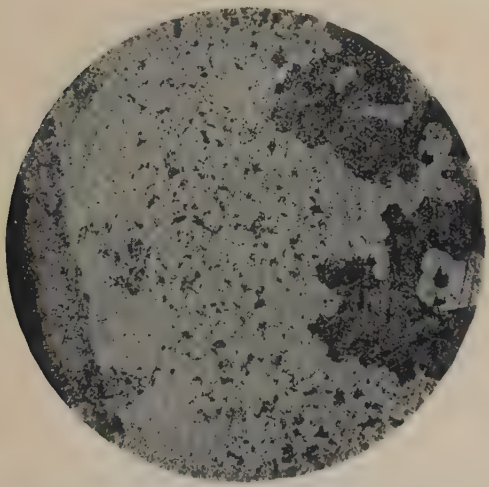

FIG. 19.—EDGE OF SECTION TOWARDS CENTRE. × 50. ETCHED 5 PER CENT. NITRIC ACID.

It was found that in general picric acid or nitric acid were used. Available literature[12] was studied, and it was found that the diversity of opinion was general. Figs. 15 and 16 show the same field of a black-heart malleable, etched by nitric in the one case and picric in the other. It will be observed that the grain boundaries are thicker and less uniform in the picric etch. The sulphide globules also have a fictitiously thick boundary. Both reagents have brought out the

rough appearance due to cold working during polishing of the very soft ferrite. Figs. 17 and 18 show the effect of the two reagents on the same field of a white-heart specimen. The nitric acid shows a more contrasting pearlite, otherwise there is little difference. These results, together with consideration of speed of etching and convenience, persuaded the use of an alcoholic 5 per cent. solution of nitric acid.

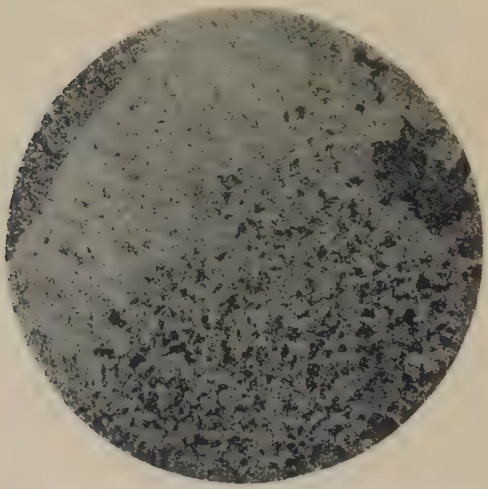

FIG. 20.—EDGE OF SECTION TOWARDS CENTRE. × 50. ETCHED 5 PER CENT. NITRIC ACID.

Magnifications Used for Examination.

As it is desirable that any recommended methods of examination should, if possible, agree with those recommended by other associations, it was decided to adopt the B.C.I.R.A. standard magnifications of 1, 25, 50, 100, 250, 500 and 1,000.

It is, however, recommended that these magnifications should be obtained with as high-power objective as practicable rather than by a high-power eyepiece or increasing the tube length of

the microscope. For the present work it was decided to use a magnification of ×50 for visual work and photographic records with higher powers if amplification of any part of a specimen was considered necessary.

Verbal Description of Microstructures.

When embarking on the microstructure work it was quickly realised that the taking of photo-

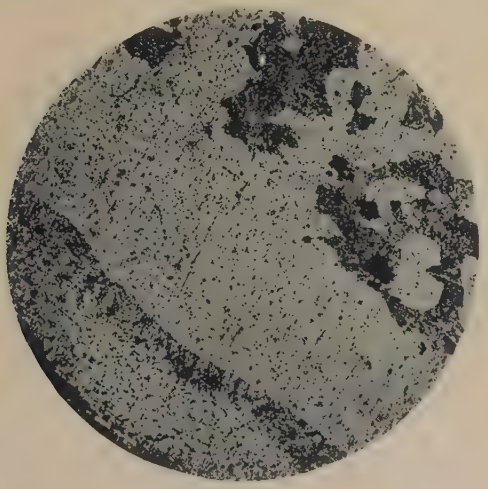

FIG. 21.—EDGE OF SECTION TOWARDS CENTRE. × 50. ETCHED 5 PER CENT. NITRIC ACID.

micrographs would have to be dispensed with as far as possible. This was on account of expense, the very large number of specimens to be examined and time involved. It was, therefore, resolved to see what could be done by means of visual examination and written reports. It soon became apparent that there was considerable difficulty in describing microstructures in such terms that others could obtain a true picture of what was meant. The question was raised,

"Can descriptions of microstructures be standardised?" Now it is a fact that works metallographists frequently commit to writing their descriptions of visual microscopical observations, and that at any time they refer to these notes they are able to obtain a true mental picture of what they previously saw. It is obvious that they adopt a nomenclature and a style of description which is standardised in their own minds.

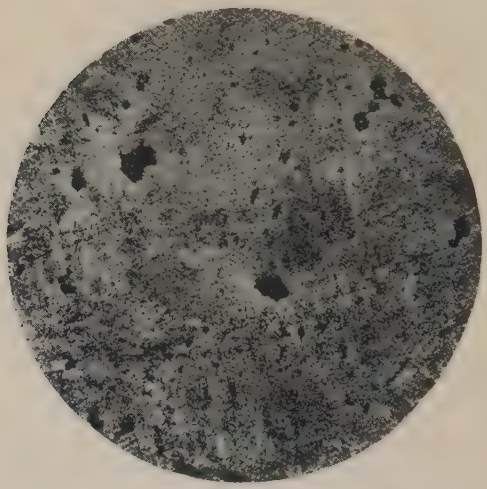

FIG. 22.—CENTRE OF SECTION TOWARDS EDGE. × 50. ETCHED 5 PER CENT. NITRIC ACID.

Why, then, should not it be possible for a number of workers to standardise? The Sub-Committee believe that this can be done, and that, once established, all who make themselves familiar with the standard terms will be able to understand any other's description of microstructure. It should be made clear that what it is proposed to standardise does not mean any alteration of the existing metallographic nomenclature, but rather an extension of it as specially

related to the structures encountered in malleable cast irons.

The idea is to apply readily-appreciated terms to describe the general arrangement of the structure. For example, ferrite and pearlite, although present in the same proportions, may exist in a variety of formations which at present cannot be intelligently described; also there are many different appearances of temper carbon. It is not impossible, further, that the

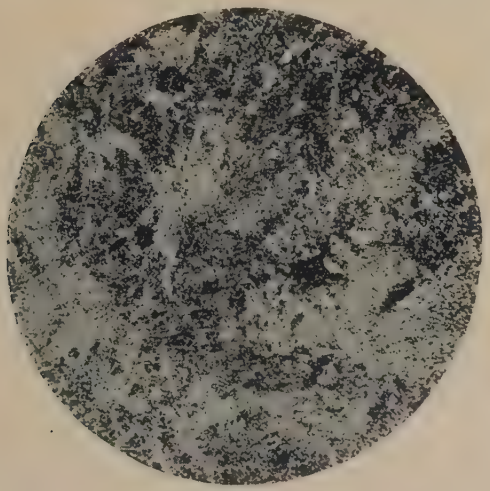

FIG. 23.—CENTRE OF SECTION TOWARDS EDGE. × 50. ETCHED 5 PER CENT. NITRIC ACID.

free carbon nodules should be counted, and that their average size should be stated.

It is obvious that some system of locating any given area for examination and comparison is necessary, and the following method is recommended (see Fig. 14). A zero mark is stamped on the outer edge of the sample at any point. This marking then formed the datum point from which any area could be located. Placing the zero to the top, the specimen is visually divided

as shown in Fig. 14. The periphery being marked clockwise in degrees and the examined surface in concentric circles, each of one mm. and numbered from the outside towards the centre. By this means the location of a point "A" is shown as 30 deg. 2 mm., or point "B" as 240 deg. 4 mm. The mm. lines were also used to indicate the penetration of the different constituents into one another. By definitely determining the measurement of the field of view

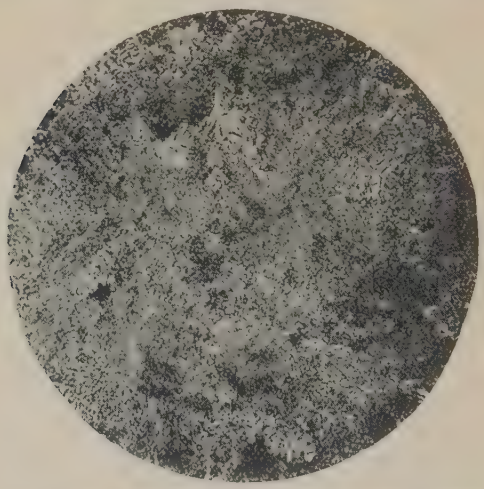

FIG. 24.—CENTRE OF SECTION TOWARDS EDGE. × 50. ETCHED 5 PER CENT. NITRIC ACID.

at any magnification, any distance from the outside can be quickly measured. The method can also be used for any irregular-shaped specimens.

Nomenclature.

Figs. 19 to 21 show micrographs of the edges of three bars, and Figs. 22 to 24 the centres of the same specimens. Study of these reveals that not only do the amounts of the various constituents vary widely, but their shape and formation differ very considerably. The work involved

in producing a standard system of adjectives, nouns, etc., to describe these variations is tremendous, and at the moment the Sub-Committee have only considered the possibilities and foreseen the advantages, but they feel that the work is well worth tackling.

No recommendations can yet be made, but the following is the outline of a possible scheme:— Depth of penetration of various constituents in mm.; description of ferrite-band, crystal-size expressed in square mm.'s, size of pearlite islands; description of pearlite-ferrite interpenetration, as fjords, deltas, lanes, etc.; description of cementite, primary, secondary, network, nodular, spheroidal, etc.; description of graphite, as primary, secondary, nodular, spidery, compact, size, number per square mm., etc.; reaction to and speed of etching, shade of colour, etc. It is realised that the above is very sketchy, but it shows the lines upon which the work may proceed.

Examination of Test-Bars and Attempt at Correlation.

The white-heart bars were marked with a series letter, as shown in Table II. The 33 specimens were then circulated to the members for examination. It is not possible at this stage to give any very detailed findings, but the following statement shows some general conclusions:—The microstructures had certain features common to all. The extreme edges of all specimens examined contained oxides and silicates in ferrite mingled with pearlite, the latter being more generally pronounced on the inner side. The depth of this structure was never more than one-fifth of a millimetre.

This was followed in all cases by a band of ferrite of very varying thickness, which merged into a pearlite-ferrite structure and varied in ratio, depth and from coarse to fine. In some cases this progressed into a core structure of pearlite with lakes of ferrite surrounding the temper-carbon nodules. In others, the pearlite-ferrite passed into an all-pearlitic matrix, and

again in others into a band of pearlite which merged into a pearlitic matrix with sometimes secondary cementite and in an extreme case with the original white-iron structure. In all the specimens the structures passed progressively one into the other. The temper carbon varied considerably in quantity, size and shape. In all cases the nodules decreased in size towards the edge and eventually disappeared at different places in the different specimens. The count of nodules in the centre varied from 3 to 33 per sq. mm.

The highest elongation results were associated with very wide ferrite rims, with the absence of an all-pearlitic zone, and the presence of the pearlite-ferrite lake-structure in the core. Generally the amount of temper carbon was less too, but the size and shape varied over the whole range from small to large and from spidery to compact.

There was a less defined relation between the tensile strength and the microstructure. In general, narrow ferrite rims, finely-divided pearlite and ferrite, and much pearlite in the core were associated with the highest tensile strengths. Where any "as-cast" white-iron structure persisted, the tensile results were low. A cementitic core is not always associated with high-tensile and low elongation as is commonly supposed. In general, the design of the ferrite—ferrite-pearlite admixture or interpenetration appears to be the controlling factor.

Conclusion.

It is felt that but little work has been brought to completion, and that this résumé chiefly contains suggestions of matters which are worthy of attention. The sub-committee has only been in existence a short time; its members live far apart from one another, and already the personnel has suffered changes. The Sub-Committee under these circumstances has taken considerable time to find a common outlook. It is thought that there is some value attached to the work already done, and that the projected

investigations are of importance. It is hoped that criticism and suggestions will be forthcoming which will aid the Sub-Committee in its future work.

The Sub-Committee gratefully acknowledges the help of the following firms for supplying test-bars, and for the carrying out of tests in their laboratories:—

Bagshawe & Company, Limited; Fordath Engineering Company, Limited (subscribing firm member); Lake & Elliot, Limited; Ley's Malleable Castings Company, Limited (subscribing firm member); Wn.. Hammond & Company (Syston), Limited; and to the following for supplying test-bars:—

John Birch & Sons, Limited; Court Works, Limited; T. Gameson & Sons, Limited; Gosforth Foundry Company, Limited; J. King & Company (Leeds), Limited; H. W. Lindop & Son; Edward Lucas & Son, Limited; Shotton Bros., Limited; also to Mr. F. Hudson, who gave much help in the early stages of the work.

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DISCUSSION.

Mr. J. W. Gardom, of Dunstable, presented the report, giving a résumé of the main points.

The Chairman (Mr. L. E. Williams, Vice-President) said that the President, Mr. Victor Stobie, had sent a written discussion to the sectional meeting which he had pleasure in presenting.

Hysteresis Losses.

Mr. Stobie wrote that the excellent contribution of the Malleable Iron Sub-Committee was a sign that the Institute of Foundrymen was as intent on leading progress in the founding industry as it was of taking its quota from the industry. The hysteresis loop for malleable iron shown in Fig. 3 was of high interest. It would appear therefrom that the hysteresis losses in malleable iron at an induction of, say, 10 kilolines should be less than those in special high-permeability magnet-steel castings. Was this a correct assumption? If so, it had been a discovery.

The remark that "the maximum permeability is superior to that of the special steel" may possibly lead to a wrong deduction. What ultimately counted in permeability for general electrical purposes was the permeability at magnetisations which would be used in normal circumstances, not at the low value for H at which the malleable iron had its highest permeability. It would, therefore, be of considerable interest to know the magnetisations necessary for inductions, say, 10,000 to 20,000 lines. Additionally, a comparison of hysteresis loops at the above inductions would be most valuable. It was more than probable that eddy-current losses would be lower in malleable iron than in high-permeability steel.

Microstructure as Acceptance Test.

Mr. A. Tipper wrote that he agreed that specified physical test figures should be raised, and that the size of test-bars should be varied according to the thickness of the casting represented. He thought that it would be possible to specify a

desirable type of microstructure, but in the experiments so far conducted there were too many variables satisfactorily to show up the relation between composition, strength and microstructure. He suggested that where physical tests were satisfactory, a microscopical examination would show whether or not the outer skin was liable to fail, due to oxide penetration. This defect was often found in material which was otherwise quite satisfactory. He considered that a careful study of the conditions favourable to rapid oxidation of malleable iron was necessary, such as effect of T.C. Si and Mn to S ratio on the liability to show " peeling " defect.

Mr. L. P. Wilks, of the Fordath Engineering Company, Limited, wrote that the information given in the report should be of great help to malleable iron manufacturers and users, and should give both food for thought. Heat-treatment of malleable castings after welding, brazing, etc., was very important, and up to the present had not received sufficient attention. Many failures had occurred due to brazing or welding of castings, when they had not been subsequently heat-tested. Attention might be drawn to the statement as to the re-solution of graphite. Would re-solution take place in malleable-iron? The paragraph on preparation of test-bars was very interesting, would it not be better to machine test-bars after annealing, particularly when such bars represented automobile and other high-class components with lugs and bosses which were machined all over. Further, it might be better to cast the three sizes of test-bars mentioned—namely, 0.235, 0.564 and 0.977 —on a common runner. This would give the advantage that all the bars would contain uniform metal, cast at a similar temperature, and after annealing could represent both large- and small-sized castings, and thin and thick sections of any particular castings. Would Dr. Norbury's graph in Fig. 1 be equally applicable to white-heart and black-heart? Figures for repeated impact and fatigue test would be extremely interesting.

An Acceptance.

Mr. J. V. Murray said that the committee was to be congratulated upon tackling such a problem as test-bars in the malleable industry, where there were so many variables in the production of the work, and it was not to be wondered that many users of malleable had their own specifications. For engineers, the B.S.I. specifications Nos. 309 and 310 were suitable, except that no yield point was included. This was a glaring omission and one that should be rectified as soon as possible. A low yield point in white-heart malleable would indicate inferior metal, while a high one in black-heart would also indicate poor material. He did not think that the standard was low. It bore a fair comparison to mild steel, certainly below 20 tons sq. in. was inferior, but the 5 per cent. elongation accompanying the B.S.I. test was more difficult to attain. The German malleable industry had recognised this and had reduced it by nearly 50 per cent. in some cases. The possibility of the inclusion of a repeated impact test, while of great value to the engineering trades, would cause dismay and ultimate collapse to many malleable-iron founders, but the rule-of-thumb method of production was bound to cease and would lead to the scientific control of the many operations involved. There appeared to be no reason why an Izod test should not prevail also. Black-heart malleable should have a hardness test imposed upon it. Should there be a dense picture-frame of pearlite present, this would immediately be discovered by the high Brinell number. The Brinell was superior to the Rockwell in this respect, because of the deeper impenetration, the latter being a surface test.

Melting Methods and Ultimate Value.

In discussing the possibility of having more than one grade of malleable, it should be remembered that the trade had already differentiated these and it was upon the method of

melting. Crucible and open-hearth melted malleable were assumed to be of a higher grade and this was confirmed by the selling prices. Cupola-melted metal was considered as inferior. This should not be so. There was very little difference in the mechanical tests. With suitable control, cupola metal could be consistent. Metal giving a tensile strength of 25 to 28 tons sq. in. was being produced regularly. The finest metal in the trade was often spoiled by faulty annealing. Temperature control was vital. There should be no sign of oxygen demarcation lines such as appeared in Figs. 19, 20 and 21. This was a defect and if the article had to be plated afterwards, the deposited metal might peel away along with the oxidised layer, or might cause trouble during polishing and mopping. Even the position of the article in the oven might cause first-class material to become of the inferior type. In one series of experiments conducted on test-bars from the same cast, a loss of from 4 to 6 tons sq. in. in strength occurred. These losses in strength happened when the test-bars were placed in the second row, while the others were in the fourth or just two cans above, the distance being about two feet apart. The average results were 28.7 tons on the fourth can upwards and 23.9 tons on the second can upwards. The proposed after-treatment clause would be of the utmost benefit to the white-heart section of the trade. White-heart malleable might be galvanised, welded, heated-up and brazed without losing its intrinsic properties. There were difficulties in connection with black-heart castings, which might prove their unsuitability for after heat-treatments, but the metallurgist was required for these, as in the case for the next proposed clause, *i.e.*, a microscopical specification and its applications.

Microscopic Tests for Acceptance Condemned.

The adoption of this clause would probably lead to chaos in the malleable industry. The

microscopical changes which malleable underwent from the herring-boned white iron to the finished product were more numerous than occurred to any other casting and the changes were heterogeneous. The retention of the bend test would be a better proposition. Bend-test results did give some idea of the microstructure. Even the term ferrite was misleading. In a Paper read at the Birmingham Branch recently it was shown that malleable test-bars could be predominantly ferritic and the angle of bend nil. The gist of the Paper suggested the immediate installation of a metallurgist in every malleable foundry, and this was not what the malleable white-heart ironfounders required. They were assumed to be too expensive. What they desired was one simple test to cover all requirements, and it could not be done. The smashing of a few scrap castings, defective ones at that, was the usual simple procedure that obtained in many white-heart malleable foundries. This should not be so, and it was one reason why the black-heart section had advanced so quickly in the industry at the expense of the white-heart, and it was the bend test-bar which was so spectacular in bending over 90 deg. that was responsible.

He could not agree that no distortion could be detected about $\frac{1}{2}$ in. from the fracture. It could be when the structure was predominantly ferritic, and it was suggested that the best section was about $\frac{1}{2}$ in. from the end of the bar, where there had been no distortion at all. Photomicrograph A showed such distortion in the shape of lattice lines, and where graphite was present the small nodules caused them to look like matches. Where the structure was pearlite in its varying forms these "matches" could not be seen. Obviously there was very little distortion in a structure that could not be deformed in a cold state. Should a microscopical examination be decided upon, the two first conditions must be: (1) Absence of primary graphite and (2) absence of free cementite. Upon these two depended everything that

mattered in malleable. In conclusion, it might be mentioned that a mixture of a 2 per cent. alcoholic solution of picric acid and a 2 per cent. nitric acid in alcohol gave the best results in etching malleable. As a medium for examination of failures, the microscope was invaluable, but its introduction into test-bar specifications was impossible to the industry as a whole if the industry was to be kept on as it was at present.

Simplification of Acceptance Tests.

Mr. J. G. Pearce, Director, British Cast Iron Research Association, wrote that both the Paper and the work of the Committee were very valuable, particularly the work on the unmachined test-bar. He did not think that the existing B.S.I. malleable specifications should be blamed on the ground that they were too low. After all, until 1927 there were no specifications at all, and it was the policy of the B.S.I. to put out specifications which in the first place represented a minimum that the trade as a whole could reach. Higher specifications for special materials and special classes of work usually followed. It would be noted that, although the Report suggests that the specification is too low, none of the white-heart materials tested shows elongation figures consistently higher than the specified 5 per cent. The suggestion that variable figures might be specified for one standard test-bar (instead of adopting varying diameters of test-bar) was undoubtedly a convenience to the manufacturer, but in practice led to difficulties. The principle had been adopted in the United States for grey iron to meet the necessity for varying the sizes of test-bar to suit the size of casting and metallurgical opinion in that country was rapidly coming to the view that the British scheme of a series of test-bars was more satisfactory.

Microscopic Tests Unsuited for Acceptance Purposes.

With reference to microstructure as an acceptance test, Mr. Pearce insisted that nobody could

have a greater belief than himself in micro-examination as a source of information about ferrous materials, particularly defective materials. For research and investigation it was essential.

This, however, was very different from using it as an acceptance test, which would be very dangerous. Ever since specifications for ferrous metals had been used in this country it has been a fixed principle that the requirements of users could be expressed in terms of definite and simple mechanical tests. The user or designer usually wanted this information, and he did not require anything further. Micro-examination could not take the place of mechanical tests so that it would be supplementary to them and would therefore put an additional burden on the manufacturer. It would open the door to endless amount of argument and difficulty, whereas mechanical tests were easily interpreted and created little trouble, even with the least well-informed inspector. He did not agree that the technique of micro-examination was simple and widespread. His experience was that the number of foundries using micro-examination in daily production was very small and that the technique was comparatively little developed. The Paper illustrated this, while photographs 15 to 18 inclusive were admirable. Figs. 19 to 24 were less satisfactory.

There was no doubt whatever that the adoption of this for malleable iron would soon spread to grey iron and that the manufacturer would be compelled to make to a structure as well as to mechanical tests. He took the view that the method of production, composition and micro-structure were no concern whatever of the user as long as the specified mechanical tests were met. On any other basis the work of the founder would be virtually impossible.

With reference to the B.C.I.R.A. standard magnifications cited in the Report, these cover the whole range of grey and malleable iron, and for malleable it was usual to work on the basis of a magnification of 25 on an etched structure.

The picric-acid etch was used as most suitable for general work, but actually for ferritic irons of the black-heart type illustrated in Figs. 15 and 16 alcoholic nitric acid was preferable. When pearlite was present, picric acid was better, as is illustrated by Fig. 18, which is distinctly better than Fig. 17. The magnification of 250 had recently been replaced by 200.

Mr. D. W. Hammond suggested that in a survey of the physical tests attainable upon malleable iron to-day, due attention should be paid to the white-heart malleable iron now being produced with an initially low-carbon content, as distinct from the higher carbons which are customary in cupola white-heart malleable. The low-carbon irons produced in the past had principally been made to a black-heart mixture, whilst to-day the low-carbon irons being produced to suitable white-heart analysis in the rotary furnaces appeared to show physical advantage worthy of investigation together with annealing advantages.

Mr. T. Goodwin agreed that the standard in the British Standards Institution Specifications 309 and 310 should be raised, but did not agree that this standard was easily attained. He knew that it was easily attained by a few makers, but there were many firms making malleable-iron castings who had difficulty in meeting existing specifications. He considered that the annealing cycle in Fig. 9 was altogether wrong for black-heart castings

SUB-COMMITTEE'S REPLY.

The sub-committee appreciates Mr. Stobie's interest in the reference to electro-magnetic properties. It must be made clear that at present little data is available on the subject, and such as there are refer chiefly to black-heart malleable. The hysteresis loss at an induction of 10,000 lines per sq. cm. is less than in special high-permeability magnet-steel castings. The maximum permeability of malleable is admittedly at a low value for " H " and the permeability

curves for malleable and the special steel cross at " H " equal 20-30 c.g.s. units. The magnetisations necessary for induction at 10,000, 12,000 and 14,000 lines per sq. cm. are approximately 8, 16 and 40 c.g.s. units respectively. The sub-committee expect to obtain much more data on the electro-magnetic properties, which may be published at a later date.

Mr. Pearce was mistaken in stating that there were no specifications for malleable castings until 1927. In 1923 B.E.S.A. published a Specification No. 5,022 for white-heart and black-heart malleable for automobile castings, and it is of interest to note that the requirements in strength and ductility were the same as were used four years later in the 1927 309/310 Specifications. With regard to the comment that none of the white-heart elongation-test figures shown in the report were consistently higher than the B.E.S.A. Specification, it should be borne in mind that the tests recorded were made for a distinct and definite purpose. Those recorded in Table I were taken without reference to the class of malleable which was represented, and those recorded in Table II were intentionally under-annealed, as explained in the text. The Committee are aware of the criticisms which can be levelled at the " standard bar with varying requirements," but still feel that it is necessary fully to investigate the matter.

Dealing with the microstructure as an acceptance test, the sub-committee wish to make it perfectly clear that they have made no recommendation whatever on this point. It is appreciated that the idea is revolutionary, and is bound at the present time to receive condemnation from many quarters. A reference to the Report shows that the Committee decided to discuss " the creation of a microscopical specification and its application: (*a*) in conjunction with standard mechanical tests; (*b*) as an acceptance test; and (*c*) as a means of investigating service failures in cases where the original mechanical test results were satisfactory." In spite of the present criticism the Committee remain assured of the desirability of investigations into this

field. Mr. Pearce takes the view that microstructure is of no concern whatever of the user as long as the specified mechanical tests were met. All users will not subscribe to this view,

Fig. A.—Illustrating Mr. Murray's Remarks.

and there are in existence at least two private specifications for malleable castings which include a microstructure clause, and it is significant to note that one of these was first published 10

years ago. The sub-committee do not agree that the micro test is expensive, nor that the technique is not widespread. It is, however, admitted that there is room for development in the technique of micro-work. Whatever the outcome of the sub-committee's work in this field, it is felt that it cannot help but be beneficial if only in stimulating and encouraging the use of the microscope among manufacturers, users and their inspectors.

Mr. Tipper's remarks do not call for any special reply, except as regards the question of the study of rapid oxidation of malleable iron, etc. At the moment this is definitely outside the scope of the work of the Committee, which is concentrated upon specifications, their requirements and the methods of their application.

Mr. Wilks queried the re-solution of graphite. Re-solution does definitely take place when malleable is heated beyond certain temperatures; the extent of this re-solution is, of course, dependent upon the temperature attained and the duration of the heating. Regarding machining of test-bars after annealing, it is considered that this question has been very fully dealt with in the Paper, but the aspect raised by the use of components which are machined all over suggests a very interesting point. The sub-committee cannot agree to the suggestion of casting three sizes of test-bars upon a common runner, firstly, because they are not satisfied as to the desirability of varied sizes of test-bars, and, secondly, because of the difficulty of ensuring soundness, especially in the large bars. This question is very fully dealt with on pages 2 and 3 of the Paper. The graph shown in Fig. 1 (which has been incorrectly credited to Mr. Pearce and Dr. Norbury, but which rightly is the work of Mr. A. E. Peace) is based on tests of black-heart malleable only, and is, therefore, not applicable to white-heart. As explained on page 259, it would be necessary to prepare different charts for the various qualities of materials covered. This would, of course, be very inexpensive, and once prepared would be permanent.

Specified Yield Points.

Mr. Murray suggests that a yield point should be included in the specifications, but yet deplores the difficulty of obtaining the present specifications, and is dismayed at the prospect of an inclusion of an impact test. If the present specifications are difficult, surely the inclusion of a specified yield point will increase the difficulties. Many users already specify hardness tests, but the sub-committee consider that a microscopical examination would render this unnecessary, since the hardness is almost a direct function of the micro-structure.

The sub-committee cannot agree that malleable is divided into prices according to the method of melting. It is felt that at the present time price is largely controlled by keen buying and intense competition.

The sub-committee quite agree that good-quality material can be produced from the cupola, and consider that this is an additional argument in favour of the adoption of more than one grade of malleable, as the criterion of purchase would then be quality.

The statements covering the variations in annealing are, of course, an additional argument in favour of the recommended microscopical examinations, as, by these means, it is possible to cover every conceivable variation within the oven.

After-Treatment.

The absence of any criticism of the section of the Paper dealing with the after-treatment of malleable, either written or verbal, proved the absence of any real general knowledge of this important subject, and that such convictions as are held are very largely based upon fallacies and not upon sound technical reasons.

The introduction of the microscopical specification will not necessarily lead to the employment of expensive metallurgists in the malleable industry. The sub-committee tried to make it clear that what is aimed at is to remove the aura of mystery at present surrounding this important branch of science, and to bring the inestimable benefits of microscopical examina-

tion within the reach of the every-day founder and layman. The black-heart industry has very largely made its progress, not as a result of bend tests, but as a result of the intelligent application of the microscope.

Regarding the question of distortion the sub-committee consider that in the case of white-heart the experiments already made are conclusive, further experiments will, of course, be necessary before it is possible to make similar recommendations for black-heart.

The lattice lines mentioned in micrograph A are flow and polishing lines due to the extremely soft nature of the material, and bear no relationship to distortion. These micrographs were prepared to show the relative merits of etching reagents and not for distortion purposes. It is agreed that the absence of primary graphite is essential in quality malleable, but the preliminary examinations have already shown that the total absence of free cementite is not necessary. It is also agreed that a mixture of dilute picric and nitric acid in alcohol gives excellent results in etching, but the present recommendations were made with a view to simplicity.

Mr. Goodwin may rest assured that the sub-committee will make no definite recommendation to raise the B.S.I. Specification without a thorough and searching investigation into what tests reputable manufacturers can attain. The annealing cycle in Fig. 9 is, of course, wrong for black-heart castings. When the sub-committee found that they had been supplied with some black-heart test-bars for their work, it was decided that these might be annealed with the white-heart bars, as it would at least result in an unusual microstructure and would be of interest, if of no definite assistance.

Mr. J. W. Gardom, commenting on the above, said that the present Paper was intended as a *résumé* of the general malleable material, and that it did not purpose to indicate definite desirable compositions of material. Such research might be the subject of further work by the sub-committee when the preliminary ground was covered.

INTRODUCTION TO THE STUDY OF MOULDING AND CASTING.

By J. Pillon.

(French Exchange Paper.)

Foreword.

This thesis is not intended for beginners, and it assumes the possession of a sufficient scientific training and a practical acquaintance with the art of the standard required for admission to the Paris Foundry High School. It does not aim at initiation, its object is higher; it constitutes the first stage of a generalisation which the future will develop.

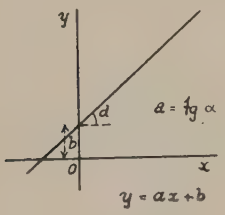


Fig. 1.

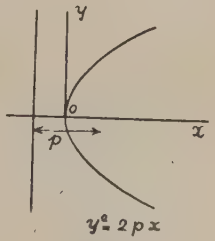


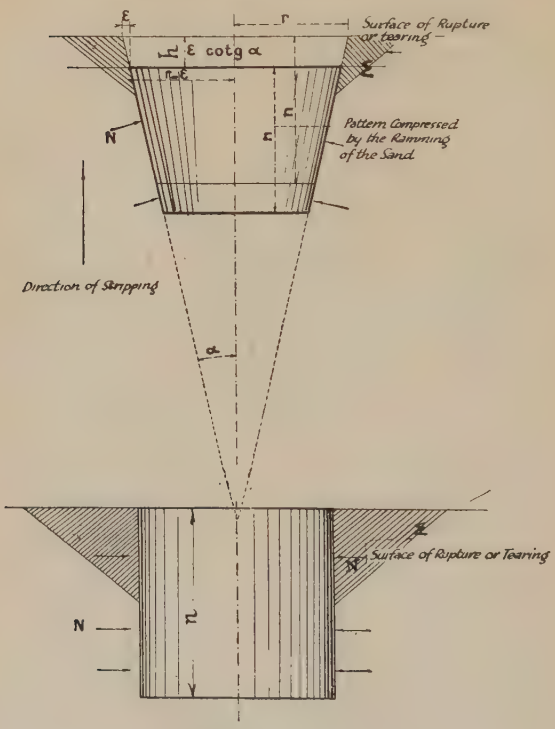
Fig. 2.

Moulding in General.

Moulding would be the simplest thing possible if it were possible to mould against the object to be reproduced, by means of a material sufficiently elastic to be stripped without difficulty from all shapes. This ideal system is only available to the ornamental sculptors who use gelatine for the production of permanent moulds in one piece to receive castings of fine plaster of paris.

Another procedure, dating from remote

antiquity, consists in preparing a pattern in moulding wax, surrounding it entirely with fine refractory earth, forming a one-piece mould, followed by heating up to melt the wax and thus obtaining, by the complete destruction of


Surface of Rupture or tearing
Pattern Compressed by the Ramming of the Sand
Direction of Stripping
Surface of Rupture or Tearing

FIGS. 3 (UPPER) AND 4 (LOWER).

the pattern, a space ready to receive a single bronze casting.

It is not possible to employ similar methods in metallurgy, where the preparation of moulds is subordinated to numerous conditions, as will be shown in the first part of this work.

PART I.—MOULDING AND METALLURGY.

In the whole question of moulding, the problems presented are complex and of two different natures: (1) the problems of moulding, properly so-called, and (2) the problems of metallurgy.

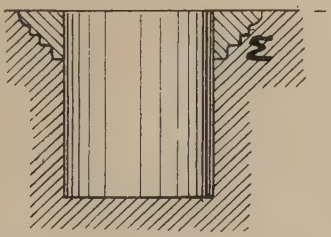


FIG. 5.

Problems of Moulding.

The object sought is the obtaining of a casting exactly similar or at least within close limits to the drawings prepared by the designer. The surfaces of this casting should be free from the faults inherent in the imperfections of the

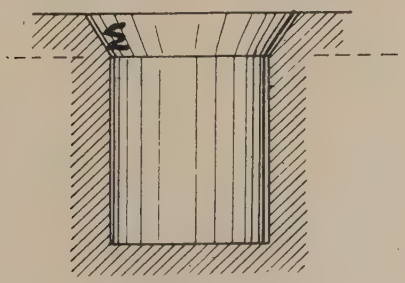


FIG. 6.

pattern, on the one hand, and the defects in the conception and execution of the mould, on the other. These include draws, scabs, erosion due to the flow of the metal, deformations and overloading due to the static and dynamic effects

of casting, blow-holes due to the impermeability of the sand to the gases and steam given off by the damp mould on contact with the metal, cold struts, unsoundness, etc.

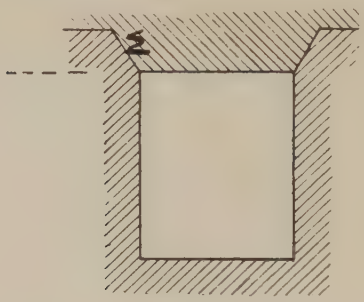


Fig. 7.

Problems of Metallurgy.

The casting should be free from segregation; in other words, it should be chemically homogeneous throughout the whole mass, free from the physical defects which come from aniso-

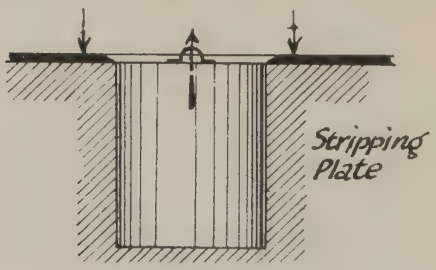


Fig. 8.

thermy, which are internal stresses, cracks, pulls, pipes, etc. It must conform to the conditions imposed by various points of view: specific gravity, hardness, mechanical strength, abrasion, resistance to external agents, magnetic

properties, etc. While both classes of problems demand simultaneous solution, the present analysis will be limited to what is concerned with moulding and casting.

Investigation of the Type of Moulding to Adopt.

It cannot be denied that a casting can be moulded and cast in many ways, and this is perhaps the reason why there has been a total absence of theory until recently. It is, however, possible to guide the moulder in the investiga-

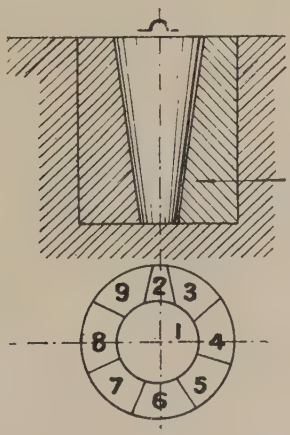


FIG. 9.

tion of the methods of moulding, and to choose amongst all those available, that which will satisfy in the best possible way the conditions imposed by what may be called the *parameters of moulding*. It will be remembered that a parameter is a constant term for each particular case considered, but which can take all possible values from one case to another. This is shown in Figs. 1 and 2. In the equation $y = ax + b$, a and b are parameters which determine one straight line, and only one. In the equation $y^2 = 2px$, p is a parameter which determines one parabola amongst all the others.

In a similar way, the method of moulding may be, among other limitations, dependant on the number of castings to be made. This number will be a parameter which, as a deter-

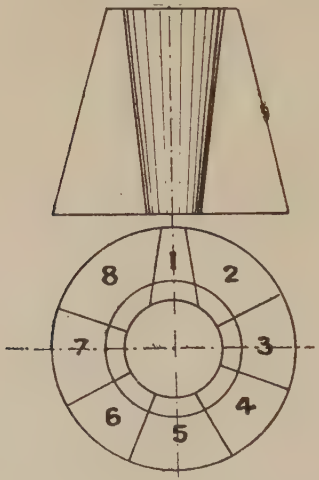


Fig. 10.

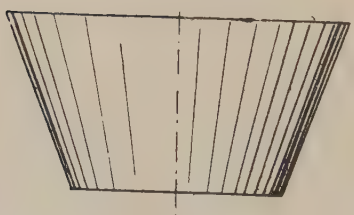


Fig. 11.

mining factor in the moulding, may lead to the latter being done by strickling, on a pattern plate, with an ordinary pattern, frame pattern, or skeleton pattern, etc.

The parameters of moulding implicitly include those of patternmaking and of casting. In a

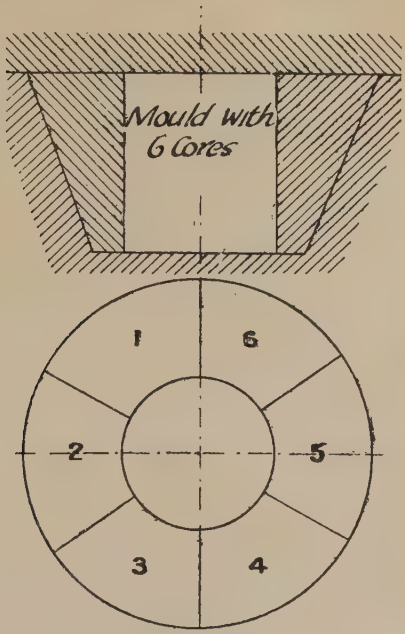


Fig. 12.

Fig. 13.

study more complete than the present one, they ought to be accompanied by those relating to the metallurgical problem, the solution of which

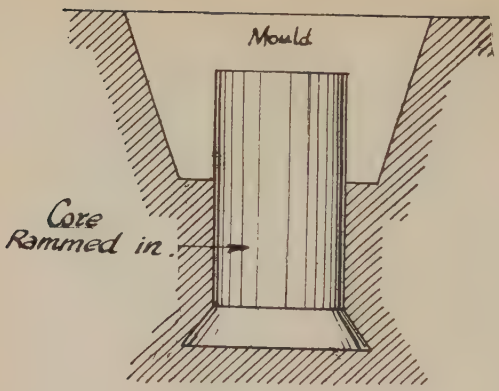


FIG. 14.

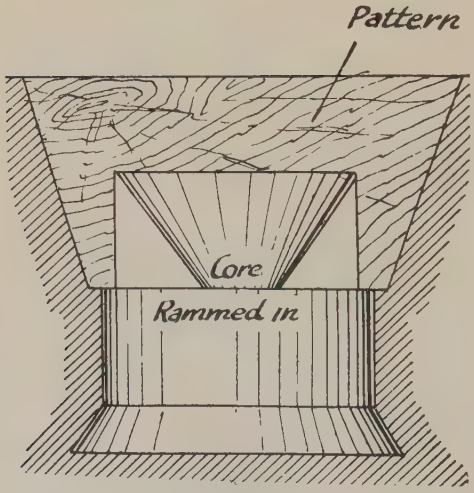


FIG. 15.

is at present engaging the attention of eminent personalities.

In conclusion, it is not a question of establishing rules for the method of the moulding of

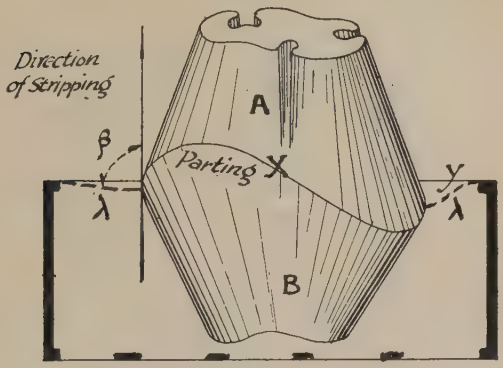


Fig. 16.

a given casting within intangible limits, but, by a methodical examination of the parameters, of deducing the solution or solutions which satisfy

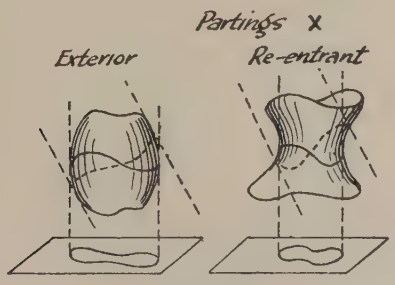


Fig. 17.

the maximum number of them. It might be objected here that what has been cited is only what is done, under another name, by those who have acquired what is called the knowledge

of the trade, practical experience, skill, etc. The reply to that is easy: It is proposed here to put in a logical form which can be easily assimilated, things which could formerly only be acquired by long years in the shops, which

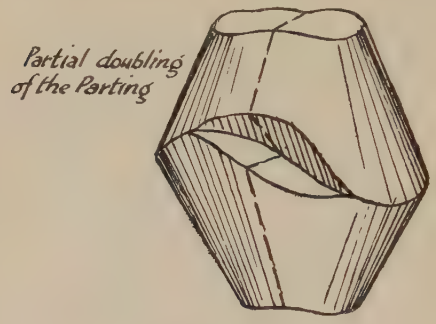


FIG. 18.

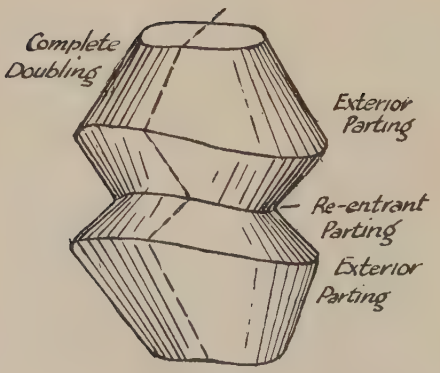


FIG. 19.

formed one of the greatest obstacles to the scientific and practical evolution of the trade.

The Parameters of Moulding, Properly So-called.

Excluding the metallurgical parameters, the following can be cited for pure moulding:—(1)

The selling price (to be kept a minimum); (2) the size of the castings; (3) the importance of the order from the point of view of quantity; (4) the maximum simplicity in moulding; (5) the

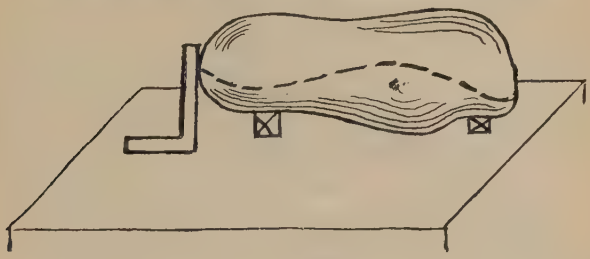


Fig. 20.

tolerances imposed; (6) the delivery period imposed; (7) the soundness of the metal and ease of machining; (8) the skill of the operatives; and (9) the materials available, etc.

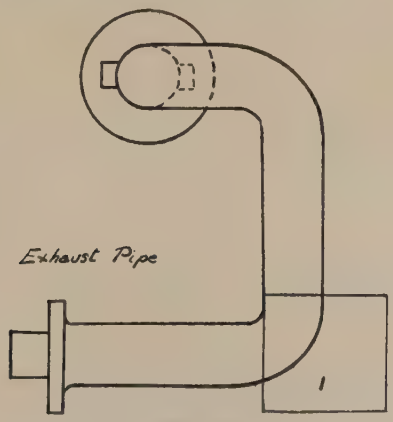


Fig. 21.

The highly-developed study of moulding at the Paris Foundry High School is nothing other than the presentation, too long to describe here, of the conditions imposed by each of the parameters of the above incomplete list in order to

determine the best method of moulding (*i.e.*, in boxes from patterns set horizontally or on end, with running planned in regard to gates, running green-sand or dry-sand moulding, etc.).

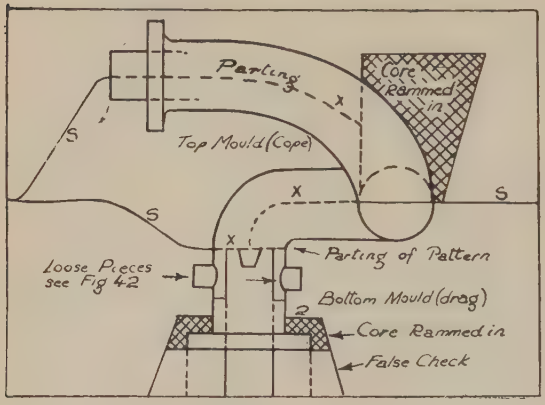


Fig. 22.

The Pattern.

Apart from all classification, the pattern is the tool which, materialising the shape of the casting, that is to be buried in the plastic material forming the mould, in order to imprint

Fig. 23.

therein the complementary shape, allowing for core prints, machining allowances, shrinkage and taper, which are the four parameters of pattern-making. The first three are imposed by the

shape of the casting, the machining to be done, and, finally, the changes in the physical state on cooling after casting.

Stripping.

The last parameter—taper—which it seems useful to define geometrically, determines the greater or lesser ease of the delivery of the

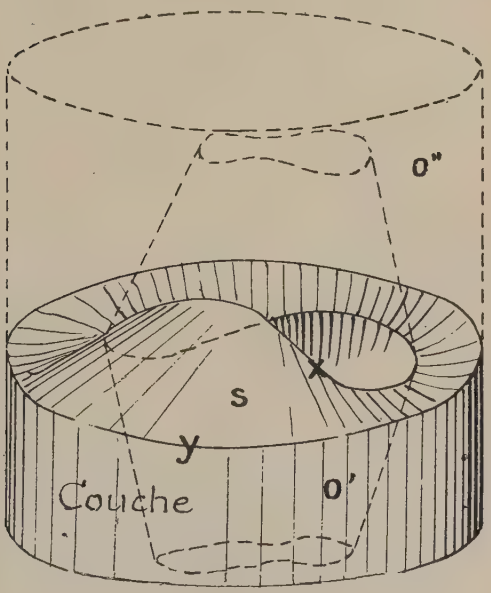


Fig. 24.

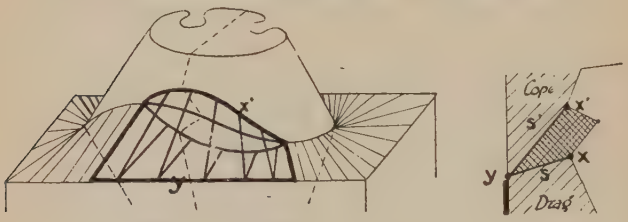
pattern from the sand. Absolute taper is that represented by the surface of a cone with point downwards, it causes a tearing force at the beginning of the stripping, which is a function of the pressure due to ramming (N) and of the coefficient of friction (f). This tearing effort continues during a certain portion of the stripping up to the moment when contact ceases. If

ϵ is the elastic reduction in length of the radius in each straight section as the result of the ramming, then, obviously

$$h = \epsilon \cot \alpha \text{ (Fig. 3).}$$

Taking a cylinder instead of a cone, friction on delivery continues during the whole period of the latter as is shown in Fig. 4.

Relative taper is that represented by the surface of this cylinder, which is the extreme limit of the possibilities of natural stripping. In all cases there is tearing of the sand along a surface of rupture ϵ. At least, if the precaution has not been taken in the first place of reducing friction, f, by polishing the pattern, and, in the second



FIGS. 25 (LEFT) AND 26 (RIGHT).

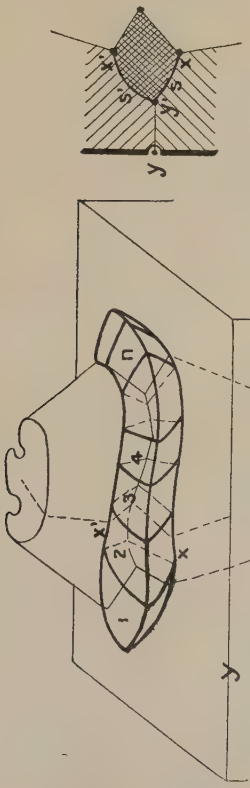
place, of employing one of the following:— (1) Rapping or preliminary vibration; (2) profiling the pattern, according to the plane of rupture (Figs. 5, 6, 7); (3) use of a stripping plate (Fig. 8); (4) making the pattern to take apart so that it can be removed in pieces (Figs. 9 and 10); (5) making the mould to take apart (Figs. 11 and 12); and (6) building in (Figs. 13, 14 and 15).

It is obvious that the reverse taper, which cannot always be avoided (locally or altogether), can be represented geometrically by the surface of a cone with the base at the bottom. Easy stripping can, however, be attained by the methods 4, 5 and 6 indicated above.

Method of Using the Pattern.

In order that the complementary imprints in the mould shall be strippable, it is obvious that

they must only enclose the pattern in accordance with the conditions of absolute and relative taper. These elements are bounded by a line called the joint, where, usually, the taper changes in direction, called the parting. This



FIGS. 27 (LEFT) AND 28 (RIGHT).

line is mostly crooked, and the surface of the joint is developed by a varying line λ passing from the flat edge γ of the box on one side to the parting **X** on the other. This joint surface is conoidal and ought only to include parts in absolute taper, with the angle β as open as possible,

in order to attain the effects indicated with regard to stripping. In what follows, this surface will be designated by the letter S and that which is moulded against it by − S.

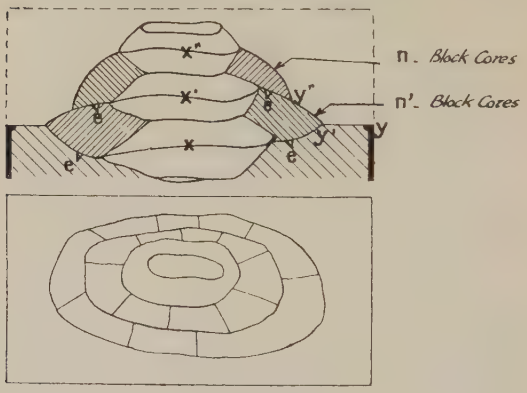


Fig. 29.

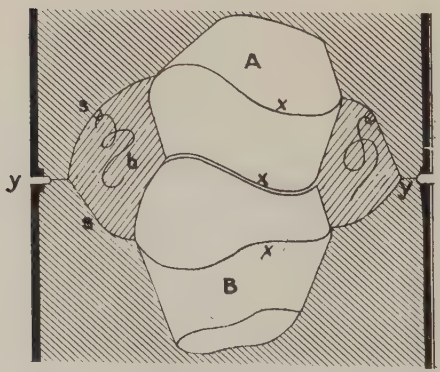


Fig. 30.

Investigation of the Joint Lines or Partings.

This investigation is subordinate to the setting of the method of moulding which is determined by the preceding analysis—the parameters of

moulding. In the simplest case the parting is single and completely visible, when it consists of one intersection as shown in Fig. 16. If the surface is curved the parting appears as a con-

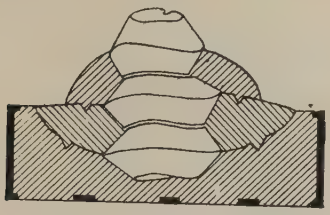


Fig. 31.

tour fixed by the enclosing cylinder, the generating lines of which are parallel to the direction of stripping as shown in Fig. 17.

Often the parting is locally as in Fig. 18, or totally as in Fig. 19 divided into two, it becomes

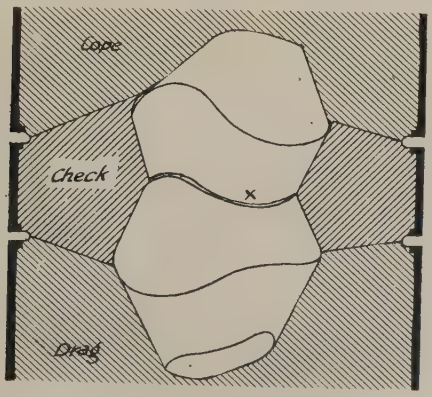


Fig. 32.

multiple and constitutes what is called the system of partings for the mould under consideration. The investigation of the system of partings is relatively easy on a pattern such as

that shown in Fig. 20, by means of a surface plate and square, but it becomes often very difficult if it has to be made from drawings.

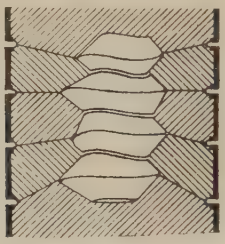


Fig. 33.

This demands great care and a skill in reading drawings, which can only come from a perfect knowledge of descriptive geometry (Figs. 21, 22 and 23).

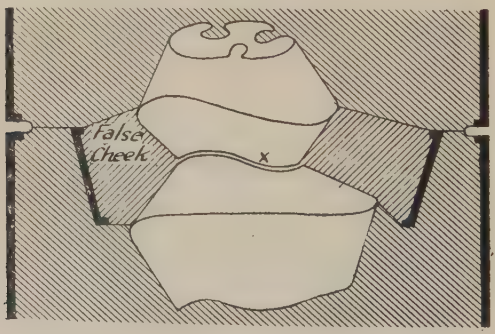


Fig. 34.

Note.—There are cases where, instead of a system of partings, recourse is had to a system of joints; for example, by using separate moulds or moulds composed of cores.

Hand Moulding as a Function of the System of Partings.

(1)—*Parting in one plane.*—The pattern is cut along the parting and moulding is done on a board, which acts as a bed.

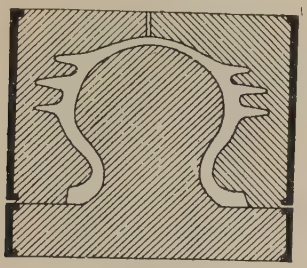


Fig. 35.

(2)—*Parting consists of a single crooked surface.*—The pattern as a whole is placed in a bed of sand or in plaster of paris, which takes the place of the board in the preceding case

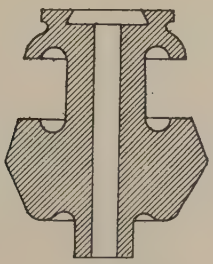


Fig. 36.

(Fig. 24). The speed of moulding can be doubled by using two patterns and two complementary plaster beds.

Partial Doubling of the Parting. (Figs. 25 and 26)

Use of block cores.—The parting is doubled and consists of one re-entrant branch and two

external portions; the general method applicable is:— 1st, Preparation of a joint surface which follows the lower external parting; 2nd, preparation of another joint surface on similar lines

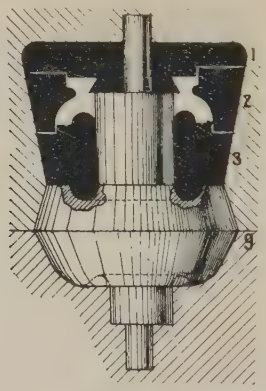


Fig. 37.

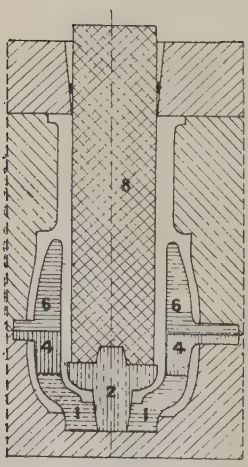


Fig. 38.

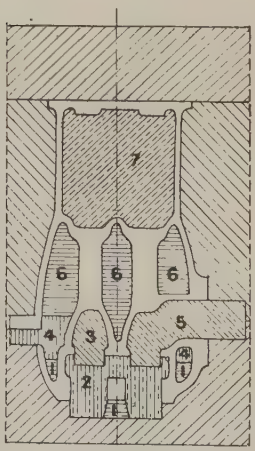


Fig. 39.

but following the upper external parting; in other words make a block core, which reduces the rest of the moulding to that of the case with a single parting.

Total Doubling. (Figs. 27 and 28.)

The pattern has three partings, two external and one re-entrant; the moulding is reduced to

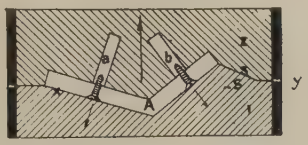


FIG. 40.

that of the preceding case by using as many block cores as may be necessary for easy stripping.

Multiple System of External and Re-entrant Partings. (Fig. 29.)

The moulding is reduced to that of the preceding case by using as many superimposed rings of block cores as there are re-entrant partings. [NOTE.—The determination of the

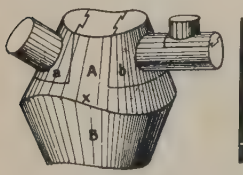


FIG. 41.

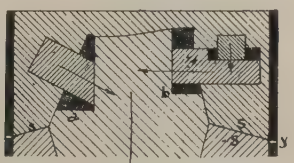


FIG. 42.

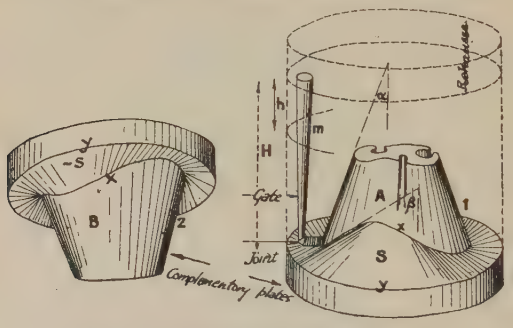
system of partings fixes the consequent splitting-up of the pattern and the moulding methods which will be referred to later.]

Simplification.

The rings formed of block cores already indicated as simplifiers, can be made in single pieces

if the precaution is taken of cutting the pattern along the re-entrant partings (Figs. 30 and 31).

Moulding with Cheeks—Moulding with False Cheeks—Separate Moulds (Parted Moulds).—



Figs. 43 (right) and 44 (left).

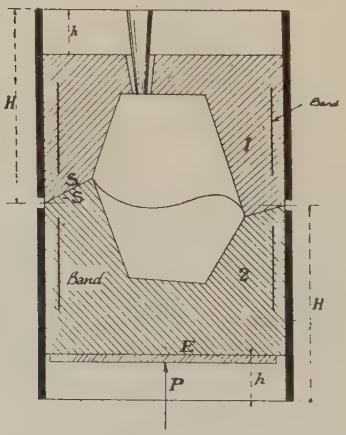


Fig. 45.

The internal reinforcement of the preceding rings is very conveniently replaced by external reinforcement, which, in the form of a flask, is called a cheek or middle part (Figs. 32 and 33).

It is frequently advantageous to replace the middle part by false cheeks either enclosed or not, by the box (Fig. 34). Finally, the use of boxes placed sideways still further simplifies the

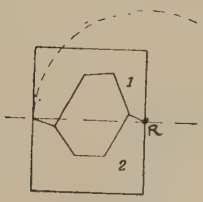


Fig. 46.

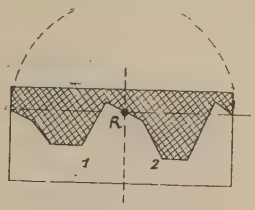


Fig. 47.

preceding moulding operation. This is the method called split moulding, already indicated as appropriate to the investigations of the joint lines (Figs. 35 and 12).

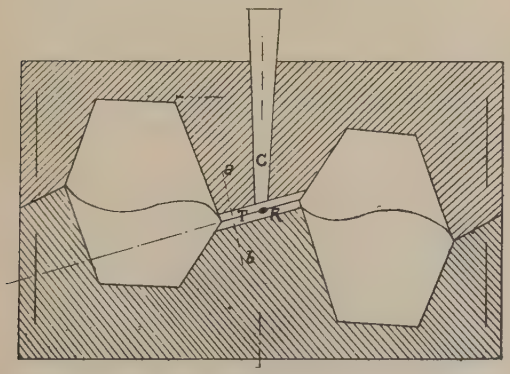


Fig. 48.

Intensive Moulding—Use of Block Patterns. —This method overcomes the difficulties and delays of the preceding; the block cores are replaced by cores moulded in separate boxes. With regard to the pattern, it is also obtained

by moulding against the actual pattern, provided with block cores in order to form the core prints. In the limiting case, the pattern against

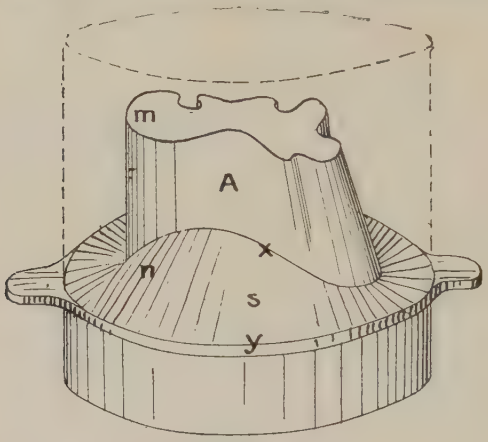


Fig. 49.

which it is moulded has none of the shape of the actual pattern, the whole surface consisting of core prints. This is the method of moulding

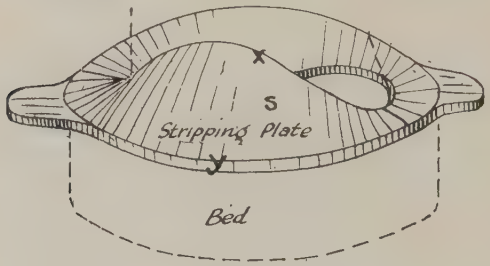


Fig. 50.

with block patterns already referred to above (Fig. 12). A great simplification of the pattern can often be obtained by packing in all or part of the cores as shown in Figs. 14, 15, 36, 37,

22 (1) and 22 (2). The cores referred to, whether packed in or not, can quite effectively be metallic in certain places, and thus form partial chills,

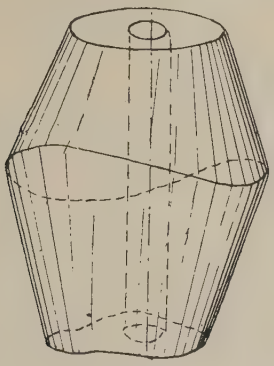


Fig. 51.

giving the mould the composite character necessary to obtain desired local properties on the casting.

Internal Cores. (Figs. 38 and 39.)

Reference may be made, in passing, to internal cores which, placed above or adjacent to each

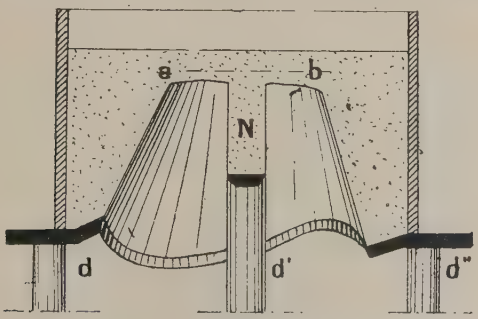


Fig. 52.

other, inter-penetrating, form a whole, the solidity of which is only secured by attached or loose prints placed in the top and bottom moulds,

possibly also in the middle parts, where use can also be made of pieces forming partial chills, removable and elastic as may be required. In

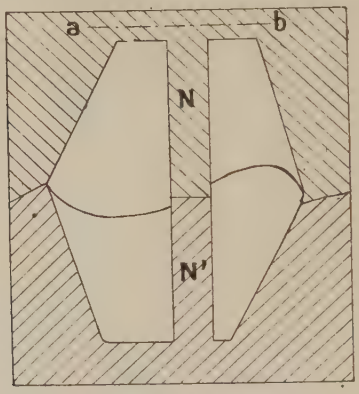


Fig. 53.

the same manner as block cores, the cores must be reinforced to enable them to withstand handling and the static and dynamic effects of casting.

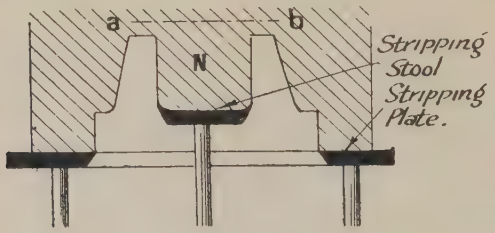


Fig. 54.

Methods for Simplifying Casting.

Parting of the Pattern (*Figs.* 9, 10 *and* 12).—Besides the parting already indicated, the taking apart of the pattern should be provided for as much as possible, by screwing on (Fig. 40)

or sliding on dove tails on the main pattern (Fig. 41) those pieces with reversed taper which remain in the sand during stripping, being themselves then drawn in the appropriate directions (Fig. 42), passing through the sliding parts *a-b*, which form stripping plates, and then also fall away.

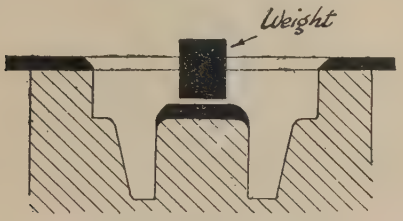


Fig. 55.

Rapid Moulding—Use of the Pattern Plate.

Simple Parting—Absolute Taper.—The pattern plate can be used both in hand and machine moulding; it represents the combination in a single piece of the pattern and the bottom board. Thus pattern plates should be visualised on which flasks are placed to receive sand rammed either by hand or mechanically (Figs. 43-44). The two boxes 1 and 2 are then

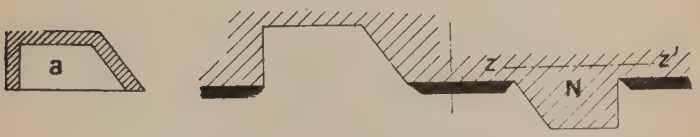


Fig. 55a.

assembled together (Fig. 45); the casting can then be made at once unless snap flasks are used to liberate the flasks, in which case a reinforcing band is placed in the flask during ramming.

Reversible Pattern Plate.

If the snap flasks are placed adjacent, as shown in Fig. 47, a pattern plate known as

reversible can be used on which double moulds can be rammed, and which can be superimposed on turning through 180 deg. Casting is effected through the gate C, arranged by means of a

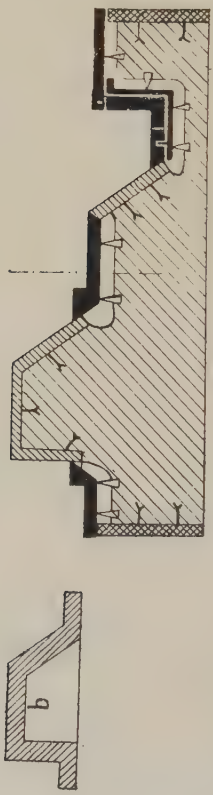


Fig. 56.

rubber runner strip placed on the axis of rotation R (Fig. 48).

Placing a number of reversible plates in an assembling frame with the axes of rotation in line with each other, gives an arrangement by

which it is possible to make multiple moulds with speed.

Use of the Stripping Plate.

1st Stage, Joint Stripper.—Whether the taper is absolute as in Figs. 43 to 48, or relative as in

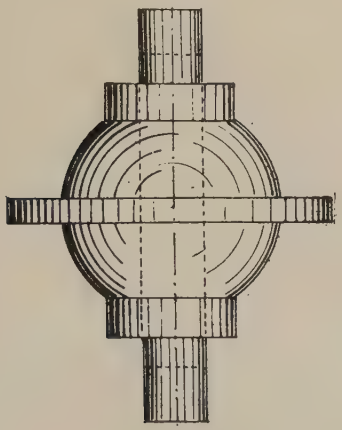


FIG. 57.

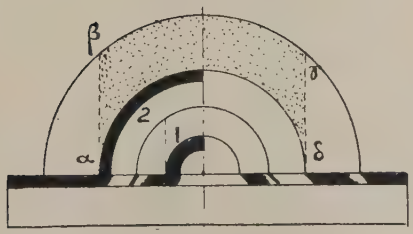


FIG. 58.

Fig. 49, stripping is greatly facilitated by using the stripping plate, Fig. 8, which really is the shape in metal of the surfaces S and −S, having sufficient thickness readily to support the weight of the mould. The stripping plate can be equally

well used on a reversible plate and on a double plate. If it is limited to the surface S, it is designated a stripping plate; it can also be used to avoid the use of internal cores where the

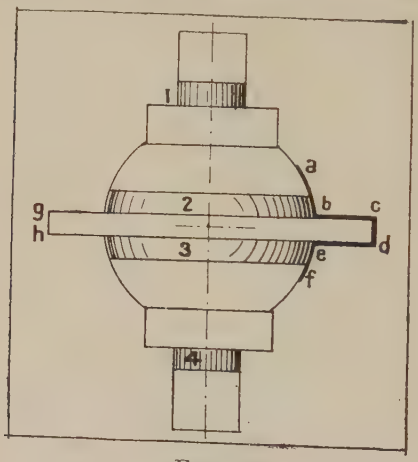


FIG. 59.

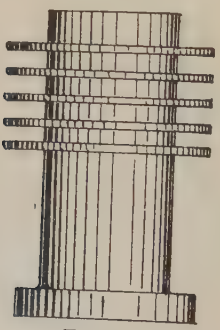


FIG. 60.

generating lines are parallel to the direction of delivery, as in Figs. 51, 52 and 53.

Extension of the Stripping Surface: 2nd Stage, Stripping Stools.—The stripping plate does not

always only reproduce the joint surface S, it can often form certain portions of the surface of the pattern. The simplest example of this is that of the cover (Fig. 54), the part of which held

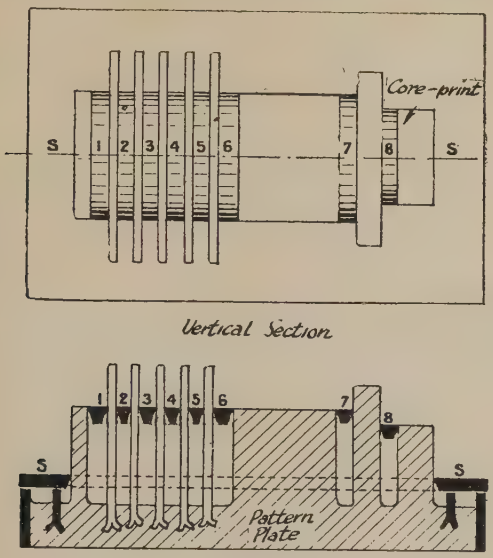


Fig. 61.

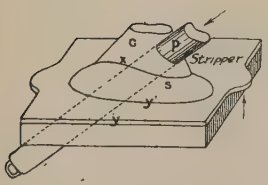


Fig. 62.

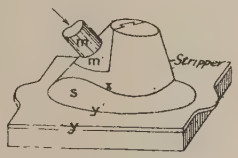


Fig. 63.

back is simply like the core of a blind hole N. The wall of this cover belongs to the pattern and not to the joint. Stripping stools are the portions of the stripper which form part of the

surface of the pattern. [NOTE.—In order to prevent breaking away of the core at *a b*, when the snap flask is separated from the stripping plate, the mould is turned over as shown in Fig. 55.]

3rd Stage, Stripper Box.—We have seen that ease of stripping very often requires the addi-

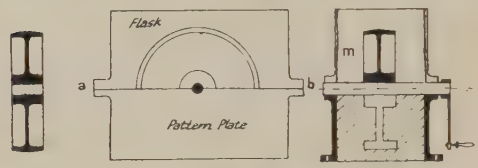


FIG. 64.

tion of a stripping plate. In Fig. 55 it can be clearly seen that the joint stripper of the moulding plates *a* and *b*, leaves a core N suspended, which can become detached along Z Z^1 due to its weight and the effect of friction.

The proper reversing plate (Fig. 56) should therefore have on the left of the axis of reversibility a joint stripper which is sufficient, and

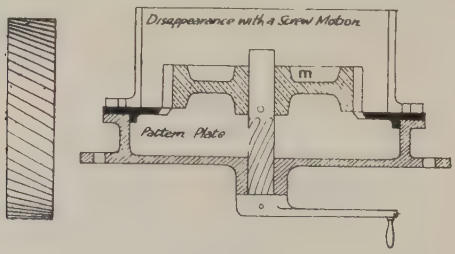


FIG. 65.

on the right a stripping plate, a piece suitably made for taking apart, which forms a real core box.

Combined Stripping Applications.—If the solid body (Fig. 57) be moulded with a pattern plate with joint stripping plate (Figs. 58 and 59), it

will be seen that the vertical portions corresponding to α, β, γ, δ (the surface indicated by dots), are not proud; to secure this, it is sufficient to add to the stripping plate the portions 1, 2, 3 and 4 of the surface of the pattern.

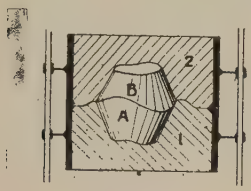


FIG. 66.

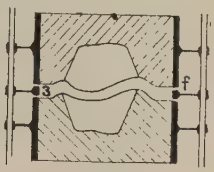


FIG. 67.

Another example is shown in Figs. 60 and 61. For the same reasons, the flat stripping plate of the pattern plate takes from the surface of the cylinder the parts 1, 2, 3, 4, 5, 6, 7 and 8. The blades are of metal and fixed in cement in the pattern plate.

Complementary Methods.

Generalisation of the Pattern Plate.—The pattern plate, as has been seen, can be used to

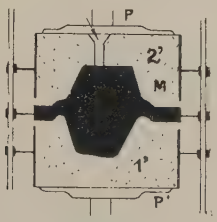


FIG. 68.

prepare the top and bottom moulds and even the cores. There is no reason why it cannot also contribute to the preparation of the middle parts or cheeks. The auxiliary processes indicated in connection with moulding on a bed fully apply,

and they can be combined with internal disappearance, often impossible with ordinary patterns, but easily obtained with the pattern plate, the base of which is accessible and which can be provided with all the internal mechanism which may be desired. The withdrawal can be in a straight-line direction (Fig. 62), by rota-

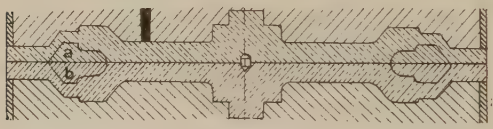


Fig. 69.

tion (Fig. 64), or with a screw motion (Fig. 65). A well-designed lay-out of the stripping stool (external and core), combined with a similar lay-out of the joint stripper and of the shell, renders solutions possible with the pattern plate which could hardly be anticipated from *plate moulding*, the ancestor of the *plate pattern* (Figs. 66 to 70).

Double-Sided Plate. (Figs. 66 to 70.)

This pattern plate plays the same part as the reversible plate. In the future it will probably benefit from the same processes of evolution. It

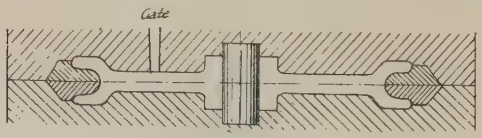


Fig. 70.

will be seen that its transformation into a core box has already been adopted in practice in the moulding of pulleys.

Strickle Moulding.

This method of moulding is only used when very few castings are required and for bulky castings. The cost of patterns is reduced to the

lowest possible, and the methods of moulding with them conform to those already described. In a large number of casts the operations consist of preparing on a reinforcement a plate in moulding sand, or sometimes in loam. The surfaces of this plate are shaped geometrically by fixed and moving templates which scrape off the excess material that has been initially rammed.

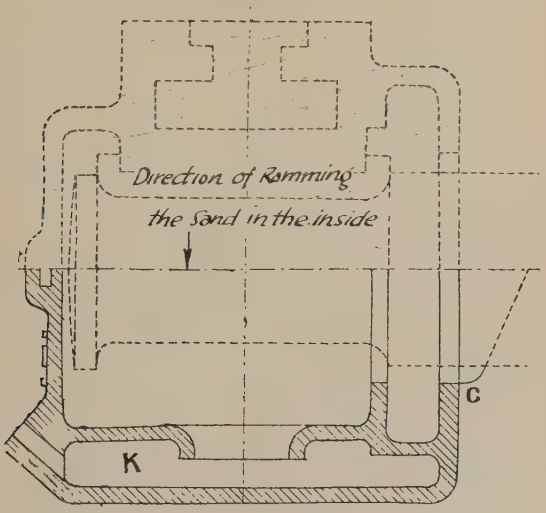


Fig. 71

The surfaces thus formed are those of the pattern and of the joint.

Figs. 78 and 79 show the generation of plane and curved surfaces, Fig. 80 that of a surface of revolution, Fig. 81 a helix. Paraboloid and hyperboloid surfaces are rarely employed, but when the necessity arises they can be made as easily as the preceding ones. Non-geometrical or auxiliary surfaces can be obtained by pressing in part patterns (Fig. 87) or by sculpture along preliminary lines with templates. Figs. 83 to 86

show the sweeping-up of a double cone, A B. Fig. 84 is the pattern plate, Fig. 86 is the top part moulded from it, Fig. 85 the strickle board

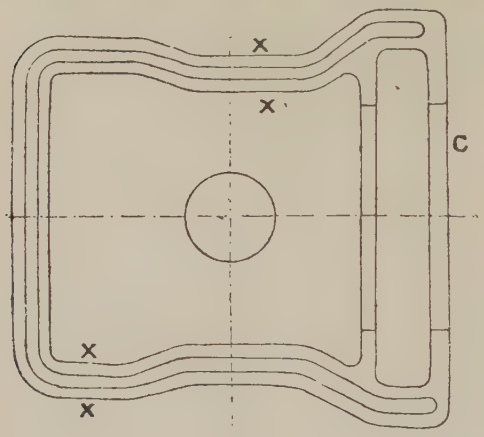


Fig. 72.

which follows the first one after the moulding of the top part, and Fig. 86 (2) the bottom part of the mould.

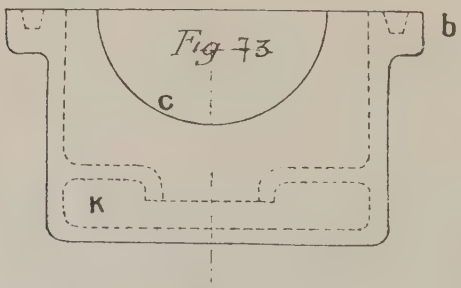


Fig. 73.

In one method strickle moulding reverts to the former methods if the top portion is rammed on a plate pattern, part of the surface of which

forms prints for a grid, or for cheeks, cores more or less complex or even for chills, superimposed in number equal to the re-entrant part-

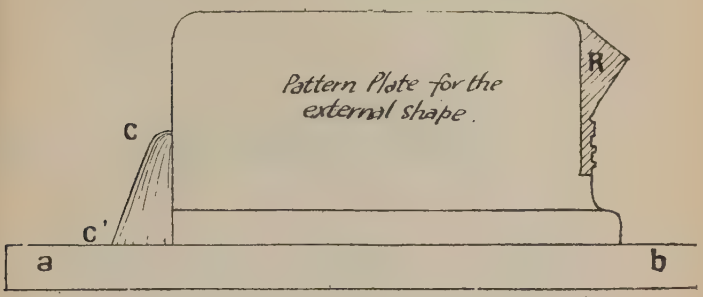


Fig. 74.

ings, in conformity with the general method already described.

A second method consists of employing block cores, cores more or less complex even chills, forming adjacent block cores, as indicated in Figs. 93 to 95, showing the moulding of a basin (Fig. 92). Strickle moulding is completely

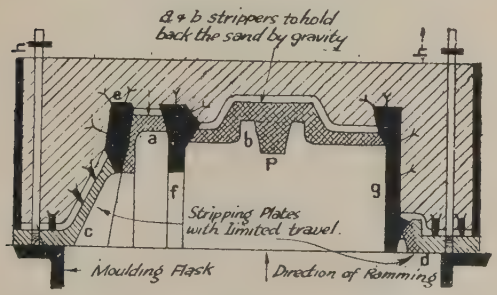


Fig. 75.

analogous to the methods already studied, and that it can borrow from them all the tricks of the trade which tend to the greatest simplification, including the use of stripping plates. The

plate is swept out by means of a board, of which the profiles 1 and 2 are successively used, as shown in Fig. 93. Then cores or block cores *m*, forming joints are set off under the parting *e*, *f* and swept, if there is room along *e*, *f*-*g*, *h* to form a whole in absolute taper, on which the top

Fig. 76.—Complementary Box.

is rammed. The latter being lifted off, a second strickling is done to remove the thickness, in so far as the core is not separately swept up to save time. This last method of operation leads to the complete elimination of the pattern plate in the case where it can be turned into a hollow shape, as indicated in Figs. 96 to 98. This is the strickle moulding, known as "without making the thickness," which is the opposite to

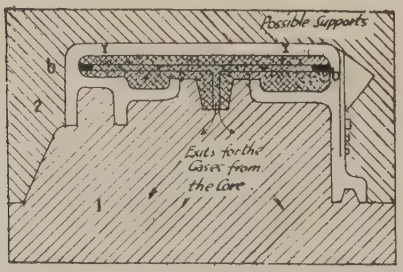


Fig. 77.—Moulding Finished.

the method called "making the thickness," in which, on a core already swept up, a non-adherent thickness is swept up and completed as required by attachments in wax, the whole forming the plate, on which the top is rammed. This is not taken off until the wax is melted

out. The added thickness is then removed and the mould closed.

When only the surface S of the joint is geometric, it is always possible to complete the plate by means of part-patterns, or by hand sculpture, using templets. It is in this way

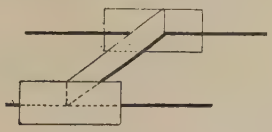


Fig. 78.

that for propellers the joint, which is helicoidal, is formed by means of a straight-edge T resting on a sheet-metal templet D cut to conform to the helices of intersection H and H^1 of the joint surfaces of the blades and of the junction with the cylinder D. The blades A are then marked out and formed by the thicknesses of sand to the shape given by the templets 1, 2, 3, 4 and 5 (Fig. 99). The centre is formed by a pattern N. The top mould is then rammed on the whole

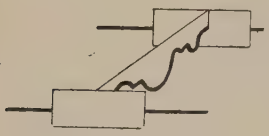


Fig. 79.

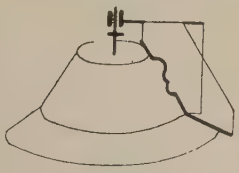


Fig. 80.

thus formed, being immediately stripped to remove the pattern N and the thicknesses of the blades.

Moulding on Frame and Skeleton Patterns.

If in strickle moulding the parts of the wooden pattern preponderate, the patterns are known as frame patterns; they form at the same time the templets on which the striking boards

slide for completing the plate pattern with added sand. If the frames are formed of laths assembled to give the thickness, they are known as skeletons.

PART II.—STATIC AND DYNAMIC FORCES EXERTED BY MOLTEN METAL ON MOULDS AND CORES.

The static forces determined by the following considerations only exist as they are here evalu-

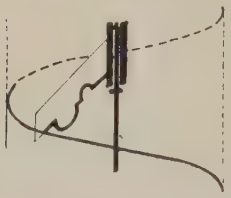


FIG. 81.

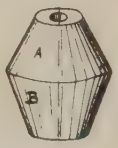


FIG. 82.

ated, under the express condition that the metal is still wholly liquid and at rest. As soon as solidification takes place, the lifting force on the cope disappears and the pressure on the drag is limited to the weight of the cast metal.

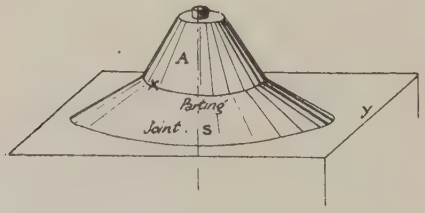
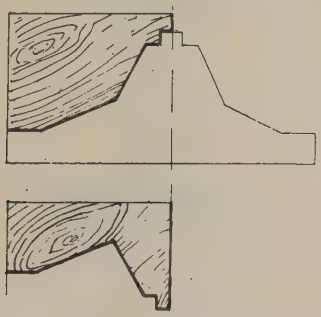


FIG. 83.

First, considering a closed space containing a weightless liquid under pressure and at rest, it can be shown that the forces exerted on the envelope are everywhere normal, since liquids offer no resistance to tangential or tensional

forces; further, according to Pascal's Law, they transmit the pressure to which they are subjected equally in all directions.

It is evident that there is no reason for this closed space to move under the influence of the



FIGS. 84 (UPPER) AND 85 (LOWER).

internal forces which are in equilibrium. The envelope, however, subject to tensional stresses which are greater as the pressure is higher, tends to assume a spherical shape. If this should happen the tensional stresses which occur in its thickness, equalise at all points and become a minimum. It is for this reason, neglecting

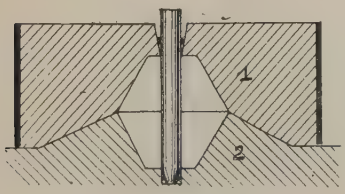


FIG. 86.

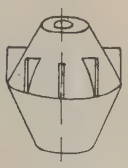
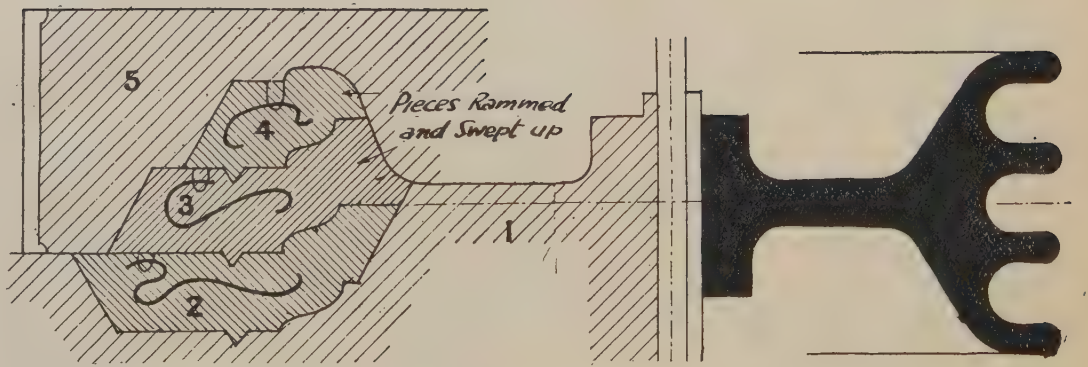


FIG. 87.

the weight of the liquid which is small, that steam boilers and compressed-air receivers should be spherical; the surface surrounding the enclosed volume would be a minimum, as would also the thickness of the wall.



FIGS. 87A (RIGHT) AND 88 (LEFT).

Under such conditions, if one visualises any diametral plane, and especially the horizontal one, the trace of which on the plane of the paper is xy, the forces S (lifting the top portion) and D (pressing down the bottom portion) due to the internal pressure, would be equal in value and $D-S=o$ (Fig. 100). It is to be noted that if there is a break in the continuity of the wall, there would no longer be equilibrium between the internal forces, in such a manner that the envelope would tend to move in the opposite direction, as has been shown by experience in the movement of fuses.

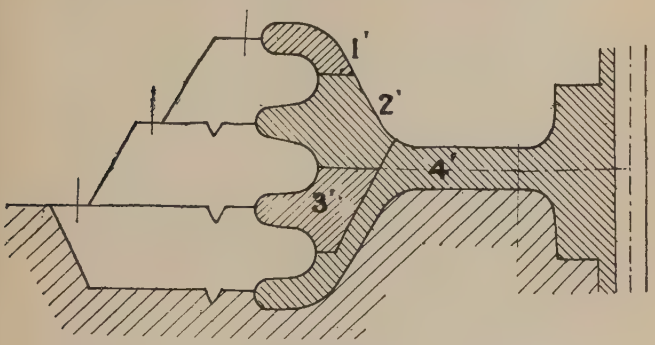


Fig. 89.

Now, considering a closed space containing a heavy liquid under pressure and at rest (Fig. 101). In this case the weight of the liquid acts at the same time as the pressure and the difference $D-S$ is no longer equal to zero. The equilibrium shape of the envelope is no longer spherical, but ovoid, and as foundry moulds are spaces which receive a liquid of considerable specific gravity pressing [normally] against inelastic walls of little strength, it is necessary to use weights and anchorages to balance S, as well as the boxes, bands grids and bars, to maintain the shape and solidity of the drag.

Calculation of Weights.

Imagine an infinitely-small element ds on a plane surface S in a quiescent liquid of specific gravity δ; the vertical distance from ds to the loading level or free surface of the liquid being

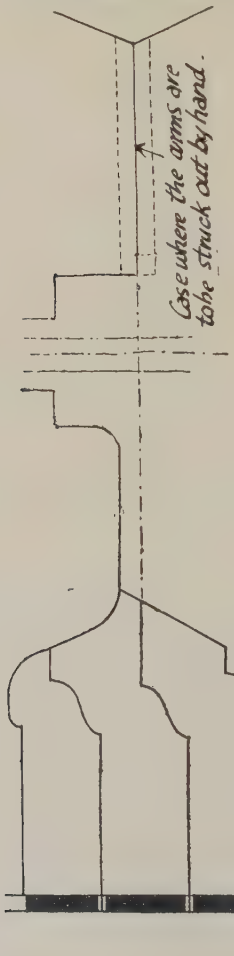


FIG. 91.

FIG. 90.

h. According to Pascal's law, the pressure on ds is normal and equal to $h.ds.\delta$. This is the weight of an elementary straight cylinder having a base ds and height h (Fig. 102).

It is evident that for the whole surface the normal force N is the sum of the weights of all the elementary straight cylinders similar to the first, *i.e.*,

$$N = \Sigma\, h.ds.\delta$$

which simply represents the weight of a truncated cylinder with the base S (Fig. 103). The centre of pressure is obviously C, the projection of the centre of gravity of the cylinder on S. The preceding reasoning applies to both sides of

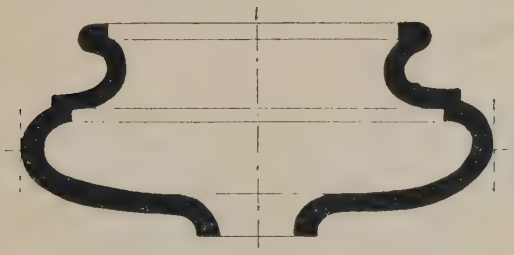


Fig. 92.

the surface S since the liquid is at rest and in equilibrium. N can be decomposed into three forces, each parallel to one of the co-ordinate axes. That which is parallel to the vertical axis has the value

$$V = N \cos\alpha = \Sigma\, h.\delta.ds.\cos\alpha$$

However, $\Sigma\, ds.\cos\alpha$ is exactly S^1, the projection of S on the loading plane. Thus the plane surface S is subjected, on each side, to a vertical component measured by the weight of a cylinder of metal of which the base is the projection S^1 of S on the loading plane, of which the boundaries are the lines of projection and which is cut off by the surface S. The point of application of this force on a horizontal plane is the projection on this plane of the centre of pressure C.

Now, examining a curved surface, the pressures are no longer parallel to each other, and as a general rule they reduce to a force and a couple (Fig. 104). It is still the same for the cylinders with a base ds, the weight of which is always $h.ds.\delta$, having three components along the axes, the vertical component being $h.\delta.ds.\cos\alpha$. However, $ds.\cos\alpha$ is ds^1, the projection of

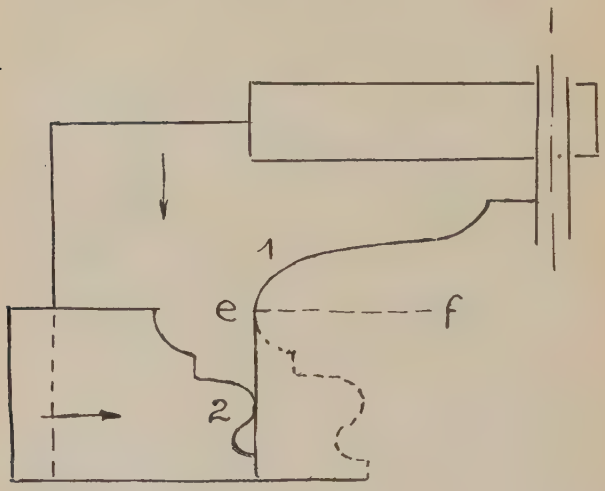


Fig. 93.

ds on the loading plane. All the elements ds together give a total

$$\Sigma\, h.\delta.ds.\cos\alpha.$$

And since $ds.\cos\alpha$ is ds^1 the projection of ds on the loading plane, one can deduce the identical conclusion as formerly, *i.e.*, the curved surface S is subjected on each side to a vertical component measured by the weight of a cylinder of metal, the base of which is S^1, the projection of S on the loading plane, of which the sides are the lines of projection and which is cut off by the

imaginary curved surface. The point of application on a horizontal plane is the projection of the centre of gravity.

Closed Curved Surface.

This surface can be either the interior of a mould or an entirely free solid body. Let P be the loading plane or free surface, and taking the cylinder projected vertically from the parting X which divides the surface into two zones, the upper one the cope, the other lower one the drag and applying the above conclusions.

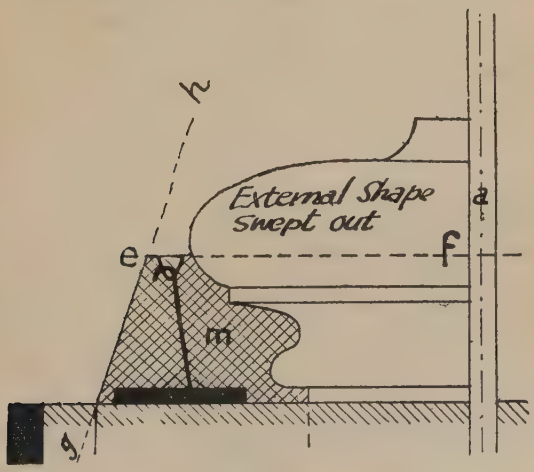


Fig. 94.

The cope of the mould receives upwards a vertical force which constitutes the lifting force, the value of which is equal to the weight of a truncated cylinder having as base the projection of the parting on the free surface, generated by the projecting lines and cut off by the surface of the cope (Fig. 105). The drag receives downwards a vertical component which tends to break it up, the value of which is equal to the weight of a truncated cylinder similar to the

previous one, but cut off by the surface of the drag (Fig. 106).

The resultant of this lifting force and downward thrust, is a vertical force passing through the centre of gravity of the mould, the value of

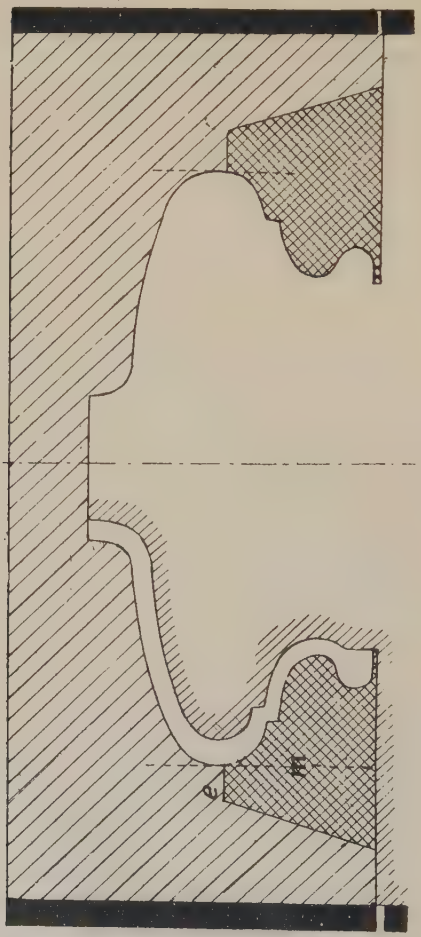


Fig. 95.

which is obviously the weight of metal cast (the difference between the hatched areas).

Here is encountered the Principle of Archimedes which is one result of Pascal's Law, much more

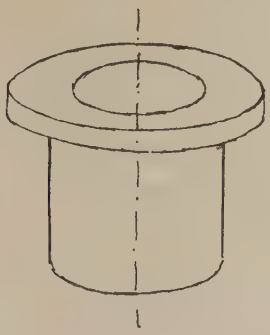


Fig. 96.

general and discovered 18 centuries later. It may be noted that the height of the loading plane (free surface) has nothing to do with the difference between the lifting force and downward thrust, but that the surface of the mould

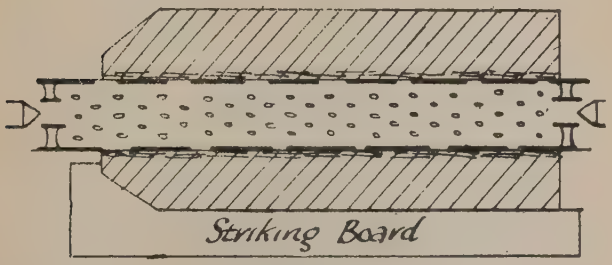


Fig. 97.

is more and more distended the greater the height of the free surface, and for the same reason the walls of the cores are more and more compressed.

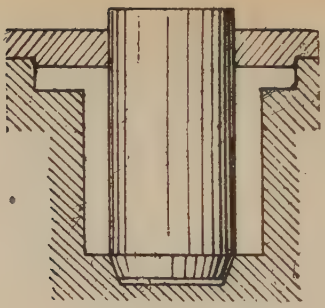


FIG. 98.

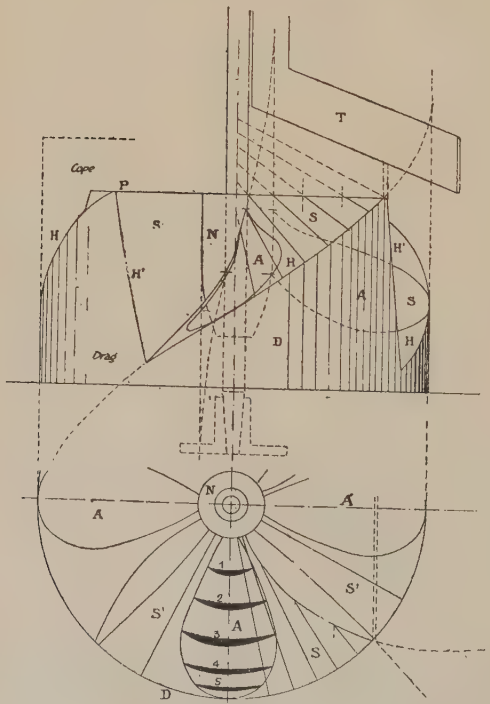


FIG. 99.

Summary of the Preceding Conclusions.

No hypotheses has been made regarding the more or less complicated surfaces of the mould; whatever these surfaces may be, the reasoning

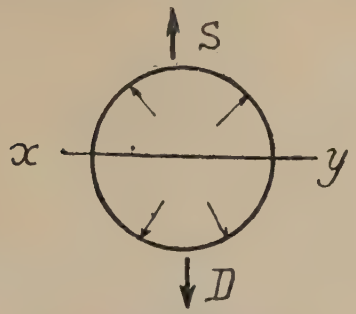


Fig. 100.

leads to the same results. The cores and projections are, therefore, to be definitely included in the calculations of the weights of the cylinders of lifting force and downward thrust (Figs. 107 to 112). It may be observed, in passing, that

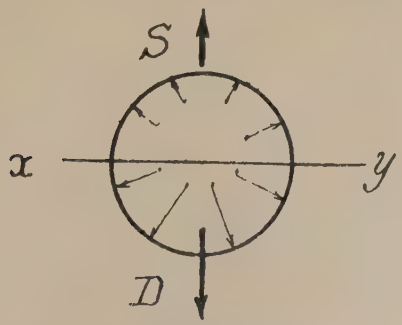


Fig. 101.

defective contact at the joint may have considerable effect, the parting then becoming the periphery of the fin and a few grammes of metal passing into the joint can increase these lifting

forces and downward thrusts by several hundreds of pounds (Fig. 113).

In conclusion it may be added that it is essential to place weights centrally with the

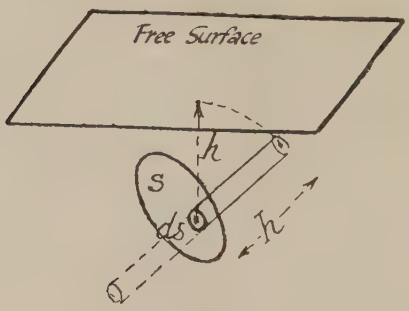


Fig. 102.

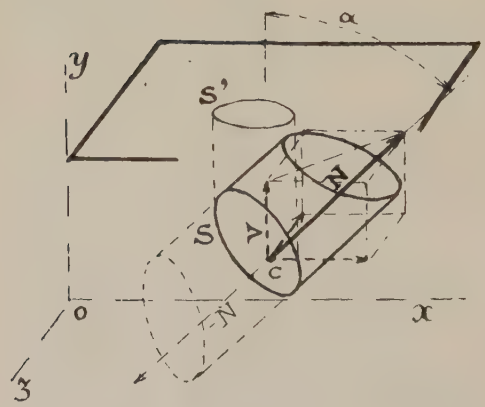


Fig. 103.

resultant lifting force, otherwise the two equal forces not in line give rise to a lifting couple tending to rotate the cope around the side most under the influence of the weights (Fig 114).

The Practical Estimation of the Forces.

The calculation of the volumes and weights of the cylinders of forces is easy when the shapes are geometrical, as, for instance, in a pan

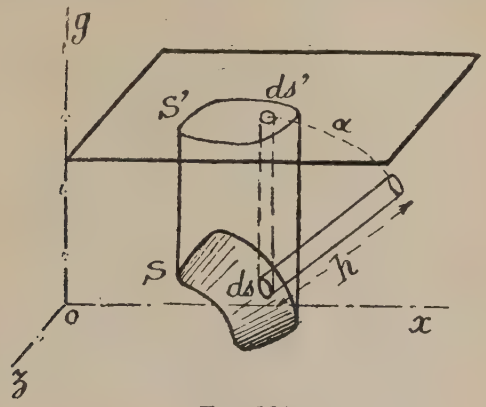


Fig. 104.

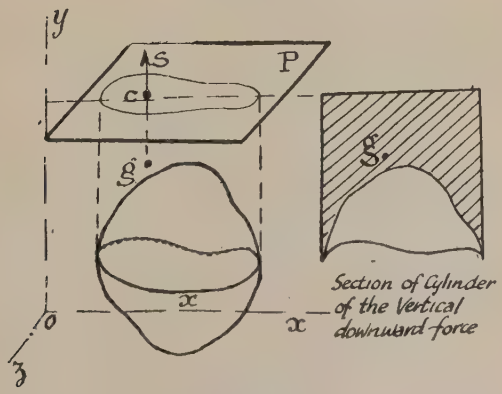


Fig. 105.

mould (Fig. 115). It can thus be found very easily that, for this casting weighing $5\frac{1}{2}$ tons, the force tending to lift the cope is 46.04 tons,

and the pressure on the drag is 51·47 tons. These forces act along the vertical axis. The lifting force on the rope could be balanced by

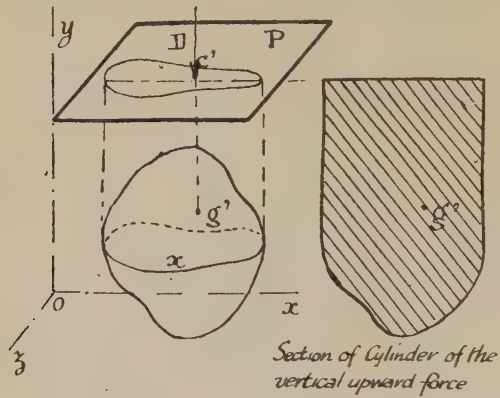


Fig. 106.

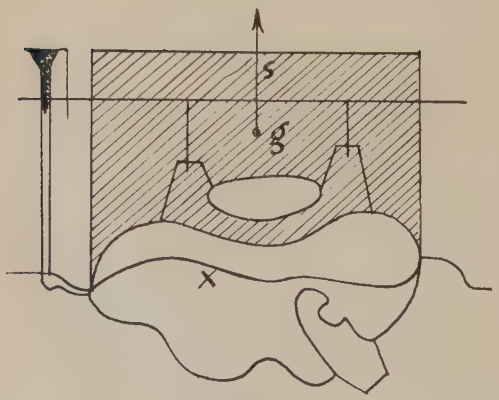


Fig. 107.

an axial load of 46 tons, including the weight of the inverted dome which forms the cope, or also by six anchor bolts distributed equally, and each taking a pull of about 7.75 tons. But in

the most usual case, the volumes are irregular, and the calculation of the weights of the cylinders of forces S and D is complicated. A number of methods can be employed to get over

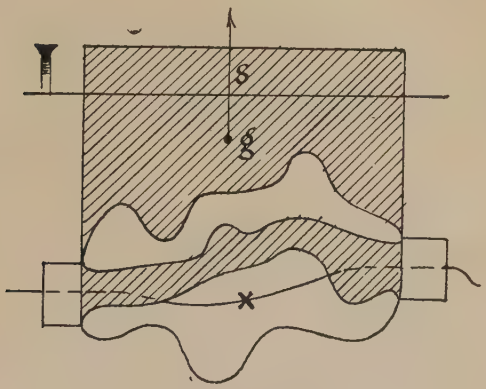


Fig. 108.

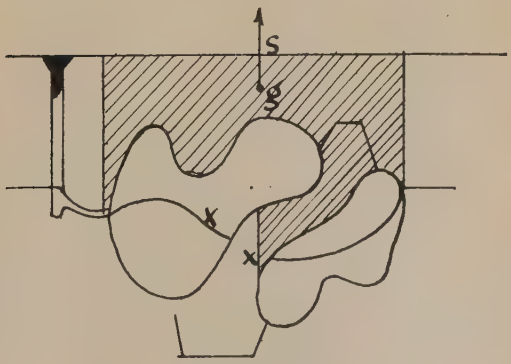


Fig. 109.

the difficulty. In the first place, using the methods of solid geometry, they can be split up into elements of volume approximately geometrical, and then combining the individual weights

by the classical methods of finding the resultant of parallel forces acting in the same direction. The total resultant force and its point of application is thus determined (Fig. 114).

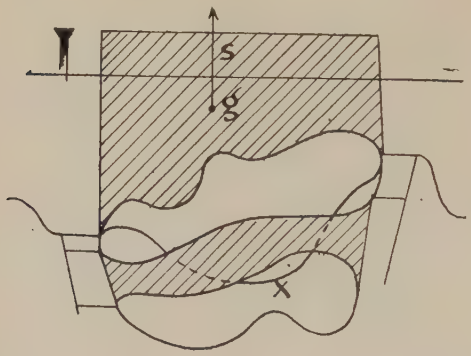


Fig. 110.

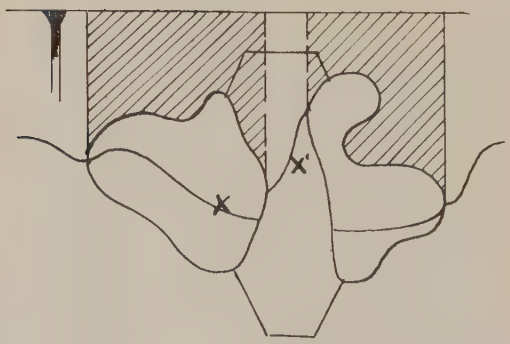


Fig. 111.

It is also possible to make a model on a reduced scale, in clay, wood plaster of Paris, wax, etc., of the volumes to be estimated, and immerse this model in a graduated vessel containing water. This gives immediately the

volume of the model, and consequently the volume sought, since the two volumes are proportional to the cubes of their linear dimensions; thus, if the scale of the model is one-tenth full size, the volume sought is a thousand times that of the water displaced.

With regard to the position of the centre of pressure on the plane of the cope, this can easily be determined experimentally, by balancing the model in question on its flat base on a straight knife edge in two directions, approximately at right-angles. The intersection of the lines of

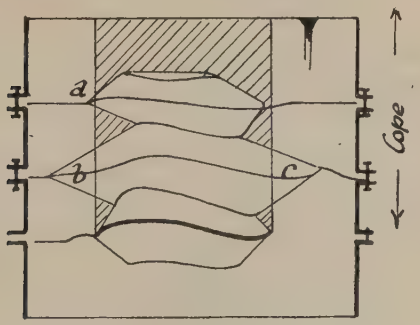


Fig. 112.

contact of the knife edge is the centre of pressure (Fig. 117). Such methods are only justified in the case of important moulds.

Various Examples.

Cylinder cover (Fig. 118): The axial core is subjected to a downward load by a vertical force of 2.8 tons along its axis, represented by the weight of a hollow cylinder, the base of which is the annular shoulder *e* and the height is the distance from this shoulder to the free surface. The axial-lifting force on the cope is 144 lbs. (equal to the hatched volume less the four webs *a*, multiplied by the specific gravity of cast iron).

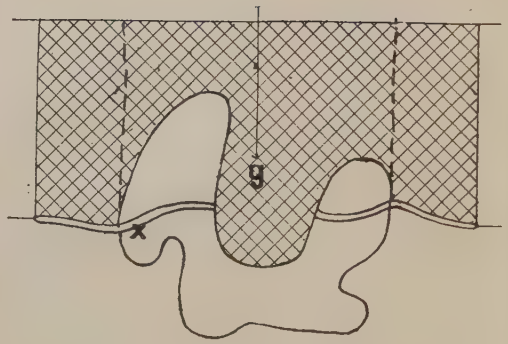


Fig. 113.

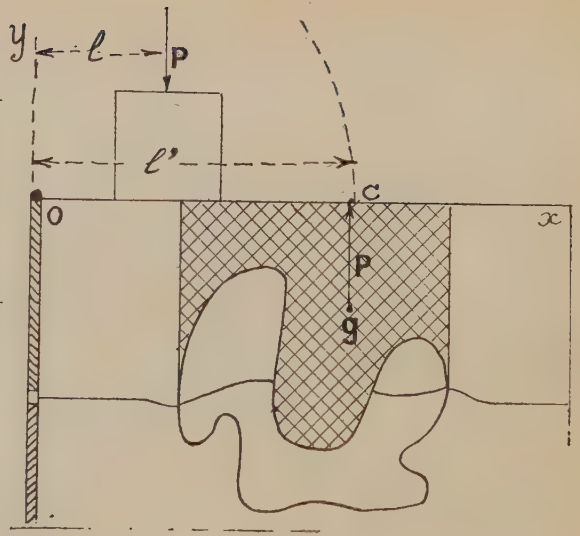


Fig. 114.

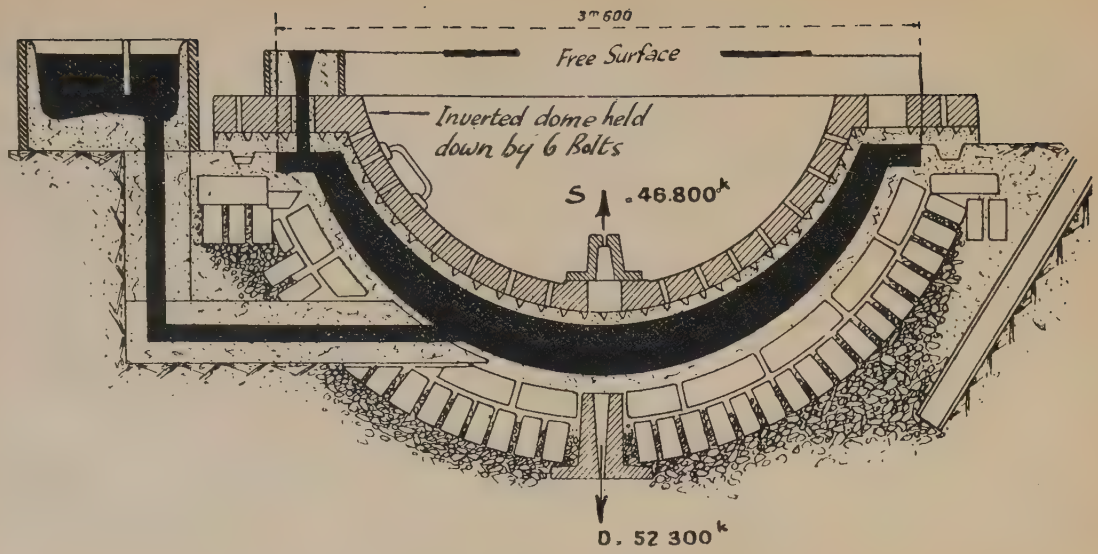


FIG. 115.—PAN CASTING WEIGHING 5½ TONS.

Half-Casing of a Hydraulic Turbine.—Fig. 119 shows the arrangement for moulding the left half-casing, weighing 2.8 tons. The lifting force on the cope acts at the centre of pressure C, the value being the weight of the cylinder on the base hatched B and of the core underneath, amounting to 70 tons.

All that has been previously said applies, as was stated at the beginning, to a casting when pouring is finished, but it is often useful to analyse the static phenomena during their de-

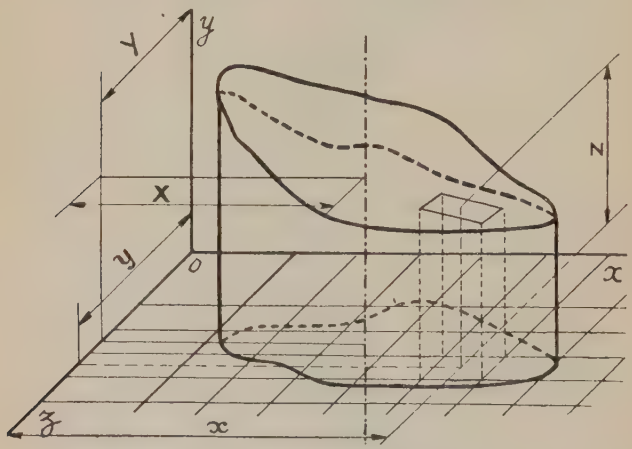


Fig. 116.

velopment. For example, visualising the moulding of the casting shown in Fig. 121, the core, which belongs to the drag, is a solid body, for which the upward force is the difference between the truncated cylinders, defined as in Figs. 105 and 106.

However, the built-in end is not subjected to pressure (Fig. 120), the cylinder of the lifting force is reduced to the tubular volume shown hatched (Fig. 121). It is possible to follow with this drawing the changes in the effects of casting by using the different levels, m, n, taken in

succession by the metal. In the same way the successive values of the lifting force and downward thrust on the parts of the mould can be analysed (Figs. 123 and 124).

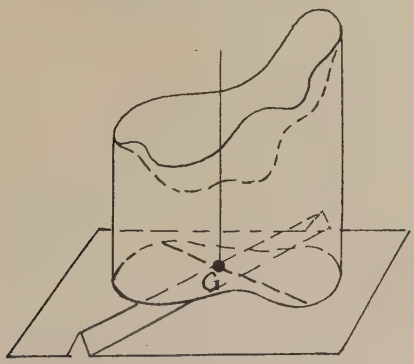


Fig. 117.

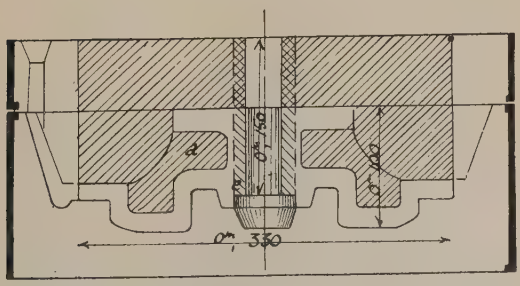


Fig. 118.

The Individual Forces Acting on Cores and Projections.

Projecting parts and cores which are detachable projections, cannot receive the same pressures as totally immersed solid bodies, and, therefore, the Principle of Archimedes can only be applied to them as a means of revealing by

difference the force and the couple to which they are subjected. Considering a totally-immersed free body having on its surface a flat portion xy. On this flat surface of area Ω it receives pressures b which are parallel to each other, and on all the rest of the surface pressures a which

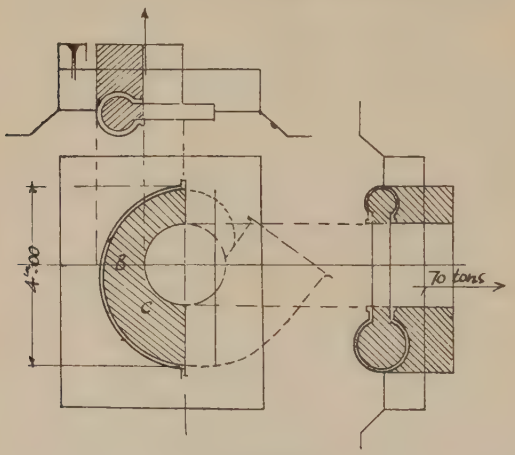


Fig. 119.

are not parallel. According to Archimedes' Principle

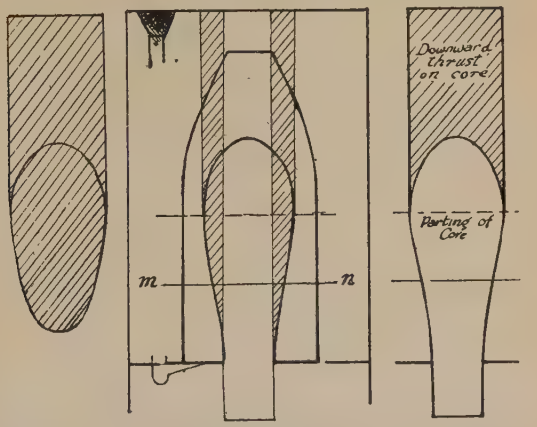
$$\Sigma a + \Sigma b = p$$

from which $\Sigma a = p - \Sigma b$

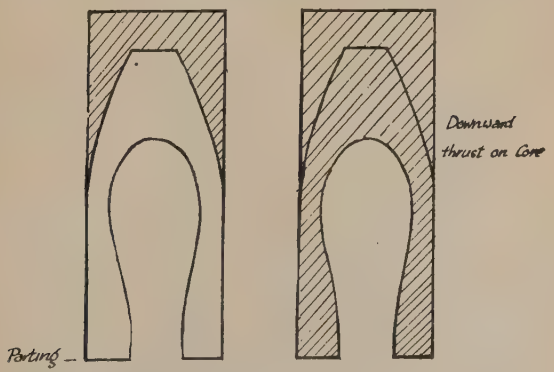
It is easy to determine the values and points of application of p and Σb by the methods previously described, p is the weight of the metal displaced by the immersed body, acting at the centre of gravity G of the body in question— Σb is the weight R of the truncated cylinder with base Ω and conic section Ω^1 . This force $-$ R acts at the centre of gravity G of the cylinder thus visualised.

If, owing to symmetry, the vectors p and $-$R are in the same plane, they intersect in the point k and the resultant ρ is directly found,

this representing the force Σa carried by a core in which the section Ω, defined by the plane xy is the base of the print π (Fig. 126). If, on



FIGS. 120 (LEFT), 121 (CENTRE) AND 122 (RIGHT).

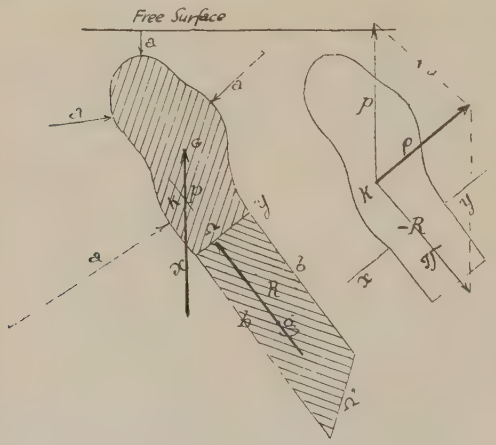


FIGS. 123 (LEFT) AND 124 (RIGHT).

the contrary, p and $-R$ do not intersect, as is usually the case, the core is subjected to a force and a couple, the vectors of which are easily

found by a very simple solid-geometrical diagram (Fig. 127). The resultant force ρ causes a component p at a distance d from $-R$. The couple is pd, which has to be balanced by a reinforcement which prevents the core turning in its point.

It can, therefore, be said that: To determine the force and the couple caused by the pressures acting on a core or on a projection, it is sufficient to deduct geometrically from the weight



FIGS. 125 (LEFT) AND 126 (RIGHT).

p of the metal displaced, the reaction caused by these pressures on the section where the core or other part is fixed, this being assumed to be plane.

Horizontal Forces—Necessity for Flasks.

Considering a ring ab of the interior surface of a mould, cut by horizontal planes infinitely close together (Fig. 128). Each element of this ring receives the normal hydrostatic force N, previously defined, *i.e.*: $N = ds.h.\delta$, a force which can be decomposed into three components, one vertical $V = N \cos \alpha$, the effects of which have

been dealt with lifting the cope and the crushing the drag, and two other components which are horizontal and parallel to ox and oz respectively. Visualising that parallel to ox, the value of it is $H_x = N \cos \beta - ds.h.\delta \cos \beta$.

However, $ds. \cos \beta$ is ds', the projection of ds on the right-hand lateral plane parallel to yoz. It is to be noted that $ds.h.\delta$ is the weight of an elementary prism of metal which, as indicated by the diagram, is exactly balanced by that which, in its extension to the left, has the

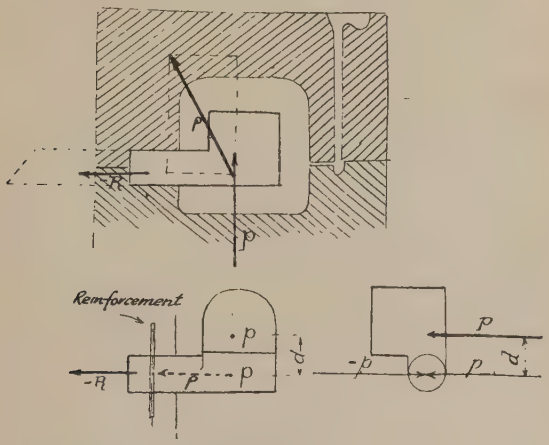


FIG. 127.

base ds. The whole of the surfaces ds and ds' form two curvilinear trapeziums, projections of the elementary ring between a and b, and the horizontal forces on these trapeziums are measured by the weight of the prisms, having for bases the trapeziums considered, and height equal to the distance to the free surface.

Applying the same reasoning to the whole, one is led to conclude that: The thrust is measured on both sides by the weight of a cylinder of metal the base of which is the projection of the outline on the vertical planes P′ and P″, the

boundaries being the projecting lines cut off by a plane at 45 deg. The centres of pressure C are the projections of the centre of gravity G on

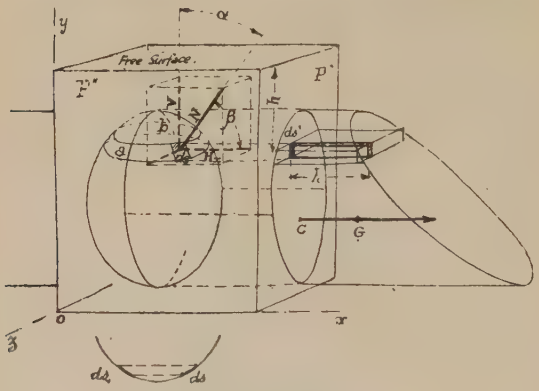


Fig. 128.

P′ and P″. If the planes P′ and P″ represent two opposite sides of the box, it will be seen that the forces and their points of application can be perfectly determined, as also for the

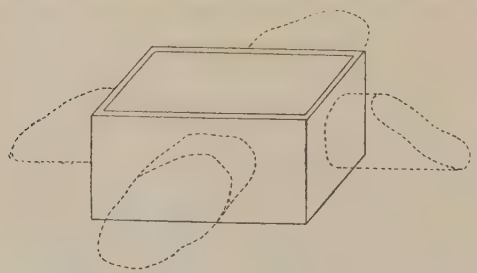
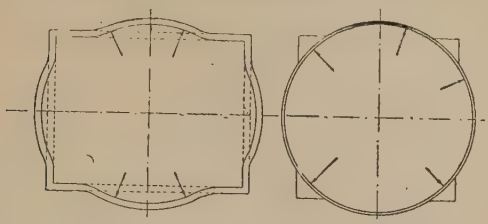


Fig. 129.

other two sides, and that it is possible to check or calculate the thickness of the box.

It may be noted that the rectangular shape does not satisfy the fundamental hypotheses of the strength of materials, since the corners form,

on the mean fibre, individual points for which the radius of curvature is very small compared with the dimensions of the straight section (Figs. 130 and 131). Each side should therefore



FIGS. 130 (LEFT) AND 131 (RIGHT).

be visualised as a solid fixed at the ends, subjected to bending and tending to deform under stress and approach the circular section, for which the thickness required would be a minimum. The circular box is therefore, in principle, preferable to the rectangular box; from

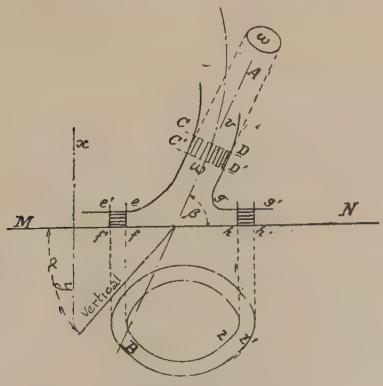


FIG. 132.

this point of view, it is like a boiler in which the pressure varies from top to bottom. It is not subjected to bending, but only to extensional forces which, in each horizontal plane, are

proportional to the distance from the free surface. In practice boxes are made with a constant thickness for their whole height.

Dynamic Effects of Casting.

The complexity of the shapes of a mould lead to a turbulent state which varies in every point

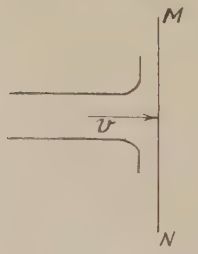


Fig. 133.

of the cast metal. One can therefore only proceed to an approximation different from what can be done in the case of hydraulic motors, where the fluid is carefully guided and under permanent control free from accidental movements.

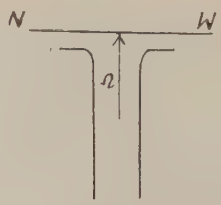


Fig. 134.

Let A, B be the direction of a down gate and M, N the trace of a plane struck by it, assuming steady conditions and parallel flow of the liquid (Fig. 132). Let v be the velocity of flow at the section C, D of area ω. The stream is split up and forms a cylindrical nappe or sheet

of height e, f, and it will be assumed that the liquid streams parallel to M, N.

During an infinitely small interval of time d, t, C, D goes to C′, D′, e, f to e', f' and g, h to g', h'. Let us apply to the mass CD $eg\ gh$ the theory of momentum along the axis x, y normal

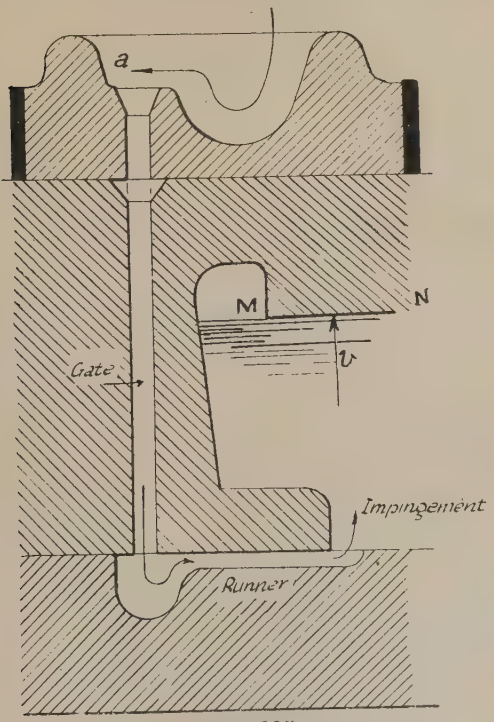


Fig. 135.

to M, N. Since the conditions are steady, it is not necessary to consider the mass C′D′ $ef\ gh$, which is common.

If δ be the specific gravity of the cast metal, the mass CD C′D′ is $\frac{\delta}{g}$ $.\omega.v.dt$, the velocity projected on x, y is $v \sin \beta$.

The increased momentum, for the time dt is equal to $\frac{\delta}{g} \omega . v .^2 \sin \beta . dt$.

The impulses exerted are F dt for the reaction of M, N and $-$ P sin $\alpha . dt$ for the weight, which will be neglected; then

$$F = \omega . v .^2 \sin \beta \frac{\delta}{g} .$$

But $v^2 = 2 gh$.

Therefore $F = 2 . h . \delta . \sin \beta$.

The dynamic effect, in other words the force with which the stream strikes the plane, is measured by twice the static load multiplied by the sine of the angle of impact. It follows that if B = 90 deg., the shock is exactly measured by double the static effect, whether the stream is descending (top pouring) or rising (bottom running). In the latter case, v should be as small as possible, since the stream has the same section as the mould.

Conclusion.

The study of the static and dynamic effects has made apparent the forces and couples which have to be resisted by moulds, core and projecting parts. It is obvious that sand alone, even when dried, cannot be expected to withstand these. Thus, the solidity of the structure can only be ensured by the use of reinforcements, such as grids, judiciously planned and calculated in accordance with the methods employed in the study of the strength of materials, joined together or placed one over the other and secured to the box and to anchorages.

DISCUSSION.

The President pointed to the author's statement, in the last column of the Paper, that "the dynamic effect, in other words, the force with which the stream strikes the plane"—*i.e.*, the plane struck by the molten metal when it passed down the feeder—" is measured by twice the static load multiplied by the sine of the angle of impact. It follows that if B = 90 deg."

("B" is the angle of impact) "the shock is exactly measured by double the static effect . . ." The President found it difficult to understand how the dynamic effect could be measured as a multiple of the static load. The static load, he said, was a definite weight, which was a matter of specific gravity multiplied by mass, but a dynamic effort was a force. Therefore, in some way the dynamic effect must have relationship to the velocity which could be gathered whilst the metal was running down the feeder, and he suggested that a calculated dynamic effect which neglected gravity—he was not speaking of specific gravity—must fail to give a correct idea. In this connection he recalled that many years ago a certain works in Sheffield, which was concerned with the making of railway springs, had had to test the permanent set of springs for a South American railway by dropping a weight on them from a given height. The people at the works had not the means for such a test, but they had a compression machine by means of which they could compress the springs until they were flat, and also beyond the horizontal, and ascertain what permanent deflection occurred. Experts in testing methods in Sheffield had tried to work out a static load which would be the equivalent of the dynamic stress intended to be imposed on the springs by the dynamic test, and had given figures so high that the makers of the springs were appalled, but when the static test was applied to the springs it was found to have only a fraction of the destructive effect which would have been imposed by the dynamic test. Therefore, he asked whether the statement in the Paper to which he had referred was a complete statement of the facts.

Mr. J. S. G. Primrose said that, taking the purely mathematical view, he would suggest that, in view of the change of direction of the flow of the metal, passing from the vertical to the horizontal, the velocity effect was very much minimised. The author had mentioned that v should be as small as possible in one case, and

in that case it was not the direct velocity, but what might be called the momentum of the moving mass, which was producing the dynamic force. Hence, the author was neglecting v, being small, giving as the pressure the force due to the momentum, which he might be perfectly right in considering to be twice the static.

The PRESIDENT pointed out that they were dealing with something which took place in actuality, and not merely abstract theory; they wanted to know how these things applied to the practice of casting. He quite agreed that Mr. Primrose would be right if he confined himself to an inapplicable abstract case, but that was not what the author of the Paper had set out to do. They could, otherwise, all find such things as had been mentioned by reference to text-books. One wanted to know the dynamic effect of the momentum of the stream, if it was perpendicular, in a metal which was disintegrating the material it was touching.

(COMMUNICATED.)

Since taking part in the discussion, I find the author states v should be as small as possible when the stream is *rising*. I believe Mr. Primrose considered that to be the presumption under all circumstances. This may explain his and my divergence of view. It remains clear that, unless the author has omitted an intended assumption, the dynamic effect must include v^2 in the great majority of circumstances.

MR. C. E. WILLIAMS (Senior Vice-President) said it was interesting to note from the Paper the difference between the working of the Latin mind and our own. It seemed to him that if the British foundryman had set out to tackle the problem of impact he would have put up a small mould and spring balances at the sides, and would have made an experiment. Mr. Williams also commented upon the value of the close contact established between the Institute and kindred bodies abroad. The trouble throughout the world to-day, he said, was the growth of

nationalism since the war, and anything that the Institute could do to further friendship between the nations was to the good. The key to the trouble was the feeling existing between France and Germany. England was the friend of both those countries; experience had shown that if two people who were unfriendly towards each other were friends of a third this joint friendship gave hope for friendship all round.

Mr. J. H. Cooper urged that the Paper was of such magnitude that it called for intensive study before one criticised it. Obviously, it contained a certain amount of knowledge which could be applied, not only to foundry practice, but to science, and if the members studied it at leisure they would certainly derive benefit, either directly or indirectly.

Mr. E. Longden pointed out that at the moment of the filling of a mould there was a great deal of unknown pressure, due to confined gases, but that had not been referred to and was very important.

Mathematics or Impericism.

Mr. F. Hudson, who said that apparently the Paper was more a mathematical treatise than anything else, referred to the conclusions stated at the end of the Paper, particularly the statement that it was obvious that sand alone, even when dried, could not be expected to withstand the forces and couples which had to be resisted; he asked how that conclusion could be reached, when the average foundryman was not aware of the forces that his sand would stand. One could obtain oil-sand cores which would withstand pressure up to 160 lbs. per sq. in. without reinforcement. To obtain the full value of the Paper, it would appear necessary that the foundryman must take a greater interest in the physical properties of the various sands used and develop an active interest in the routine testing of mould materials.

Mr. Wesley Lambert, C.B.E. (Past-President), said he assumed that the pressure of

160 lbs. per sq. in. referred to by Mr. Hudson was a static load—a different thing from a dynamic force. He went on to point out that if molten metal was falling into a mould, and impinging upon a material which crumbles under the force of impact, it would be difficult to arrive at the true dynamic value of the blow occasioned by the falling stream of metal.

The PRESIDENT said the author's conclusion was that sand alone could not be expected to withstand the forces and couples mentioned. One could scarcely regard an oil-sand mould as sand alone.

MR. HUDSON replied that he was not accepting the Paper as literally as all that. He had assumed that the author had intended to imply the materials used by the foundryman.

MR. A. HARLEY (Past-President) supported the view already expressed, that the attempt to discuss the Paper before giving it adequate study might create a false impression, and he urged that members should reserve their judgment in these matters. If those who devoted the necessary study to it could find anything which would advance our knowledge of the pouring of castings in the slightest degree, then the Paper was of value to the Institute.

Where Mathematical Considerations are Essential.

MR. F. W. ROWE, who heartily supported Mr. Harley's remarks, said it seemed that one or two members had passed premature judgment on a Paper which contained quite a large amount of useful and valuable knowledge, and that careful study would yield something of real practical value to a great many of the members. Mathematical calculations of the dynamic stresses set up in the pouring of a casting might not appear, to many people, to be of real practical use, but in his experience he had found it essential at times to abandon for the time being purely hit-and-miss considerations of dynamic stresses, and to get down to basic mathematical calculations. He was interested particularly in the centrifugal casting of metals, and had found that, in order

to obtain a true view of that particular branch of founding, it was essential to study it from the mathematical viewpoint before attempting to study the more practical side of the business. It was remarkable that, with different peripheral speeds, different sizes of castings and different methods of pouring, there were enormous variations in the dynamic stresses which could be set up in such a thing as a centrifugal casting. One wondered at times why certain cores or certain moulds would break up under the centrifugal stresses imposed, but when one came to calculate those stresses, one appreciated the enormous differences and the reasons for the seemingly anomalous behaviour of different types of sands and different types of moulds. He suggested that the very novelty of Mr. Pillon's Paper had rather startled a good many people, but that the study of foundry practice from any new angle was bound to yield something of real value.

Mr. A. S. Worcester suggested that the Paper should be discussed through the medium of correspondence, in fairness to the author, bearing in mind that members had had the Paper in their hands only a short time.

This suggestion was adopted, and the President said that a reasoned reply would be obtained from the author, to whom the criticisms would be submitted.

AUTHOR'S REPLY.

Mr. Pillon wrote that in reply to the surprising discussion on his Paper, he would advise his critics to make a closer study of it. He thanked those who had really studied the Paper for their remarks, and would point out that the work was on a scientific but nevertheless very modest level, and was intended to raise the study of moulding to a higher level.

PAPERS PRESENTED TO THE BRANCHES.

Birmingham Branch.

SOME RECENT DEVELOPMENTS IN AUTOMOBILE CAST IRON.

By T. R. Twigger (Associate Member).

The automobile industry occupies an important place in regard to the manufacture of cast iron on account not only of the tonnage consumed but also of the demands it makes for the production of a special high-grade material to meet the ever-increasing severity of working conditions. Far from cast iron being gradually superseded by other materials as at one time appeared possible, the development of special types of material has enabled the use of cast iron to be advantageously extended. This would obviously not have been possible without a better understanding of the nature of the material itself, the ability to obtain improved properties, and the increased confidence of the designer or user.

Developments during the past few years have generally sprung from the necessity for improved service although the need for renewability of wearing parts, especially on commercial vehicles subjected to heavy duty, has been a contributory factor. From both points of view the principal components to be considered have been those which are either wearing or reciprocating parts of the engine, as for example, the cylinder bore, valve seats, valve guides, pistons and tappets as shown in Fig. 1, although an important wearing component of the chassis, the brake drum has recently provided a further application of cast iron.

The improvement of cast iron is usually concerned with either:—(*a*) increasing the hardness or strength of the metallic matrix, or (*b*) reducing the size and sometimes the quantity of the graphite flakes by which the matrix is broken up.

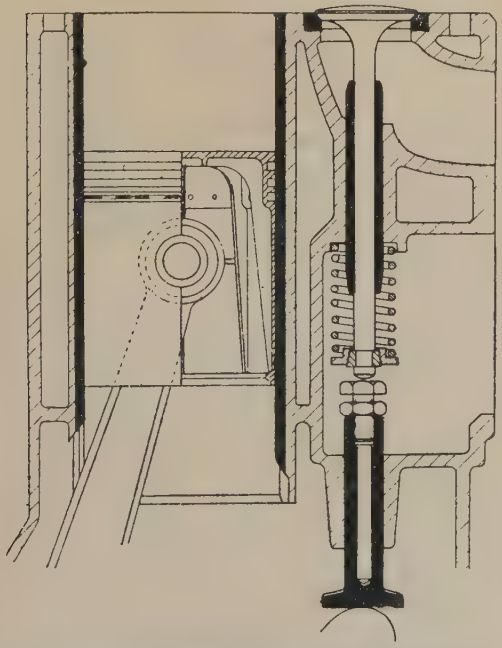


FIG. 1.—CYLINDER BLOCK, SHOWING LINER, VALVE GUIDE, PISTON AND PISTON RINGS, VALVE SEAT AND TAPPET AS THE PRINCIPAL WEARING PARTS.

There has been no lack of suggestions during the last few years for improving the quality of cast iron, in fact it has been no easy task for those engaged in works practice to weigh up the possibilities of the various proposals in the light of the engineer's demands and the potential sales possibilities for material of improved properties.

Three methods of improvement which have been established on a definite commercial basis are the use of centrifugal castings, alloy additions and heat-treatment. These are in turn discussed below with special reference to conditions (*a*) and (*b*) mentioned above.

Centrifugal Castings.

The centrifugal process which has now been in fairly extensive use for a number of years has already been described and the principle of the process is generally fairly well known. It is sufficient here to say that molten metal is poured into a mould (usually metal) rotating at high speed. The action of the centrifugal force throws the metal to the outside of the mould, where it solidifies to form a hollow cylinder. Slag and other impurities are directed to the inside of the casting and are generally eliminated by a little excess metal which flows into or over the "front plate" which closes the mould.

Apart from facilitating the production of hollow castings especially suitable for cylinder liners, valve seats and brake drum liners the use of metal moulds ensures a much closer grain than is generally possible with sand castings, also the graphite is much more finely divided thus meeting condition (*b*) as is shown by Figs. 2 and 3.

While the centrifugal process brings in its own peculiar difficulties with regard to defects the castings made by it are generally free from the porosity often found in sand castings. It will be noticed that the use of hollow cylindrical castings for cylinder liners, valve seats and brake drum liners is of great assistance in connection with the renewability of wearing parts, a point which is of great importance in the commercial vehicle industry. There is the additional advantage with these renewable parts that they can be made from material specially designed to resist wear, and provision can be made if desired for such special wear resisting components to be fitted in the original engine.

Alloy Additions.

Additions of special elements are designed mainly to improve the hardness or strength of the metallic matrix (condition (*a*)) but also to some extent to reduce the size of the graphite flakes (condition (*b*)). For example, nickel, providing the silicon is correspondingly reduced, enables a closer grain and smaller graphite flakes to be produced. Nickel and chromium are the ele-

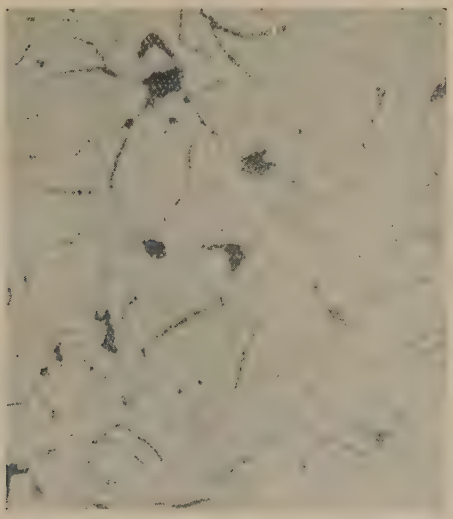


FIG. 2.—GRAPHITE IN SAND-CAST PISTON-RING IRON. UNETCHED. × 120.

ments in fairly common use, but molybdenum and vanadium are receiving attention. Nickel and chromium most certainly have their uses but it is very doubtful whether in the small percentages normally used they exert very much influence on either the strength or resistance to wear of the casting. Their chief benefits seem to be as an aid to the founder in producing sound castings where the design is such that

difficulty might otherwise be experienced. The writer has known many cases of castings where by the use of nickel in conjunction with chromium the tendency towards porosity in heavy sections has been considerably lessened.

Considered from the standpoint of wear, which is the main consideration in the commercial-vehicle engine, there is little evidence to show that nickel in itself, even when the silicon is

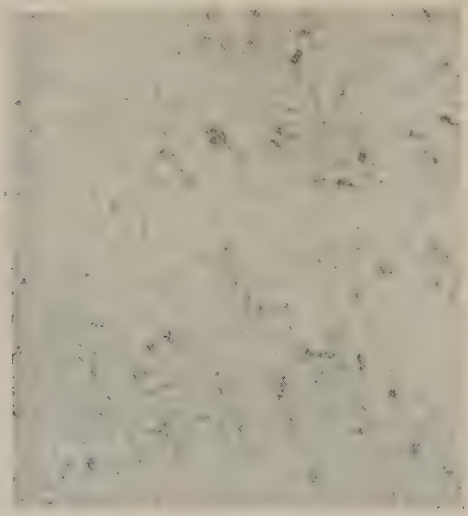


FIG. 3.—GRAPHITE IN CENTRIFUGALLY-CAST PISTON-RING IRON. UNETCHED. × 120.

reduced, increases the life. Chromium, though acting as a hardener, may exert some influence in this respect, but in the commercial-vehicle field, at any rate, small improvements, although acceptable up to a point, do not really solve the problem, because service conditions are so severe that something giving very much improved life is looked for. Chromium is useful from the point of improving the resistance to

heat, this being of relatively little importance in connection with cylinder liners, but quite important in connection with valve seats which are exposed to the high temperature of the exhaust gases, and also in connection with brake-drum liners, which frequently get a high surface temperature due to friction of the brake-shoe lining. For these two components it is suggested that the chromium should be at least 0.5 per cent. Tests carried out by Donaldson* showed clearly the influence of chromium in minimising the reduction of combined carbon at temperatures of 450 deg. C., at which ordinary iron may show an appreciable change after prolonged heating.

Thermal Conductivity.

It is interesting to notice that chromium, while increasing the hardness, leaves the material relatively easy to machine even when the chromium is sufficiently high to give a definitely

TABLE I.—*Thermal Conductivity of Various Cast Irons.*

	150 deg. C.	400 deg. C.
Ordinary good quality iron—		
No nickel. No chromium ..	0.12 units	0.107 units
0.75 per cent. nickel. No chromium	0.107 „	0.101 „
No nickel. 0.2 per cent. chromium	0.125 „	0.111 „
No nickel. 0.4 per cent. chromium	0.128 „	0.115 „
Austenitic cast iron: nickel, 14 per cent.; copper, 7 per cent.; chromium, 2.5 per cent.	0.101 „ (At 100 deg. C.)	0.095 „

mottled structure. Chromium also increases the heat conductivity of cast iron, while nickel reduces it. The percentages detailed in Table I show fairly small differences, but these are by no means too small to take into account.

* Donaldson, Proc. I.B.F., 1928–29, p. 128.

Expansion Curves.

The amounts of alloys added are, generally speaking, small, except for irons of very special properties, as, for example, martensitic irons or austenitic cast irons containing high percentages of nickel, copper or manganese and sometimes chromium. Austenitic irons have a much greater coefficient of expansion than ordinary grades of cast iron and approach the coefficient of expansion of aluminium alloys. They have, therefore, possibilities in the direction of renewable parts, such as cylinder liners or valve seats fitted into

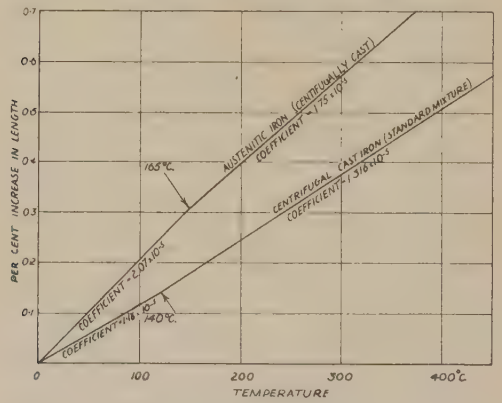


FIG. 4.—EXPANSION RESULTS IN AUSTENITIC AND ORDINARY CAST IRON.

housings of aluminium alloy. Such a construction may result in a great saving in weight. Coefficient of expansion tests on centrifugally-cast samples of austenitic iron and ordinary cylinder iron are shown in Fig. 4.

Irons which are martensitic as cast due to large percentages of nickel, chromium or manganese which render the material costly and exceedingly difficult to machine, would appear to have little advantage as regards automobile practice over other irons of more normal composition in which an equally hard martensitic structure can be obtained by heat-treatment.

Heat-Treatment.

This is perhaps the most outstanding development in cast-iron metallurgy in recent years. Heat-treatment of grey cast iron for the removal of casting strains for improving machinability has long been practised, but increasing the hardness by hardening and tempering, although the principle has long been known and was, in fact, used nearly 20 years ago by the firm with which the author is connected, does not seem to have been applied very much commercially until the last few years. This was partly due to the lack of metallurgical knowledge which now enables the process to be put on a proper footing, and partly for lack of the commercial stimulus which the present demand for better wearing properties provides. The hardening property of cast iron or steel depends on the fact that above the critical point the carbon in solution can be retained in the hard martensitic form by suitable quenching.

In the case of steel the whole of the carbon is usually in solution above the critical point. With cast iron the amount of carbon in solution will depend on the composition of the material and the temperature to which it is heated. Silicon, nickel and other elements which tend to precipitate carbon from the solid solution reduce the amount of carbon in solution at any given temperature and elements such as sulphur, manganese and chromium which normally harden cast iron will increase it. It follows that the extent to which cast iron must be heated above the critical point in order to secure a satisfactory hardness on quenching will depend on its chemical composition. In addition, the actual critical point itself is influenced by the chemical composition—silicon, for example, increasing it and nickel and manganese reducing it.

The hardening operation is usually carried out on the articles finished except for final grinding, as, generally speaking, the material is too hard to machine after hardening except by using special cutting tools or by grinding. It can,

however, be tempered to a hardness value between that of the as-cast material and the fully hardened, so that it is possible to secure a part which, although much harder than the original material, is sufficiently soft to be machinable with special tools.

This plan is adopted in heat-treating valve-seat inserts, where it is very desirable to cut the seating for the valve after pressing in the insert in order to secure perfect squareness of the seating with the valve stem.

Numerous tests have been carried out to determine the mechanical properties of hardened and tempered cast iron. Tests made some five years ago by the writer included tensile, elasticity, Brinell, etc., and also the effect of time and quenching in both oil and water, as a result of which oil quenching was adopted as the standard practice. Some results have since been published by Hurst.* Some recent tests carried out by the writer are summarised in Table II. It will be noticed that the samples, which had a chemical composition approximately as follows: Total carbon, 3.35; combined carbon, 0.60; silicon, 2.10; sulphur, 0.09; phosphorus, 0.45; manganese, 0.70; nickel, 0.50; and chromium, 0.20 per cent., contain no large amounts of nickel and chromium. In a recent publication† it is suggested that heat-treatable iron for cylinder liners and valve guides should have 3.0 per cent. nickel. In the works with which the writer is associated thousands of valve guides have been hardened by heat-treatment without any trouble with warping and distortion, and the oil hardening of cylinder liners has been a commercial operation for several years without any trouble due to cracking in hardening. While it is agreed that nickel enables a lower quenching temperature to be used, this is only of the order of 20 deg. C. for 1 per cent. of nickel added. The tests shown in Table II were made with the object of determining more exactly the effect of

* J. E. Hurst, "Oil Hardening and Air Hardening Cast Iron," FOUNDRY TRADE JOURNAL, December 4, 1930.
† FOUNDRY TRADE JOURNAL, October 29, 1931.

tempering at various temperatures, and in order to try and get some evidence of the degree of brittleness of hardened and tempered cast iron as compared with as-cast.

The test-pieces for modulus of rupture, elasticity value and permanent set were in the form of annular rings cut from the castings. The modulus of rupture is obtained by pulling apart in a small tensile machine a split ring as

TABLE II.
MECHANICAL TESTS ON HARDENED AND TEMPERED CAST IRON.
(CENTRIFUGALLY CAST)

Sample 5.0/E.65.	Brinell.	Modulus of Rupture Tons per sq. in.	Elasticity Value. Lbs per sq. in.	Permanent Set at 14 tons per sq. in.	Direct Tensile Tons. per sq. in.
As cast.	230	29.3	16.1×10^6	13.6%	15.6
Oil Hardened 830° C	426	26.0	12.7×10^6	17.1%	12.6
Oil Hardened 830° C Tempered 350° C for 15 minutes.	437	33.5	13.9×10^6	4.6%	16.13

Sample 4.5/G.85.	Brinell.	Modulus of Rupture Tons per sq in.	Elasticity Value. Lbs per sq. in.	Permanent Set at 14 tons per sq. in.	Increase in gap opening at fracture
As cast.	240	30.5	16.4×10^6	13.3%	.859"
Oil Hardened 830° C	472	25.2	14.0×10^6	12.6%	.824"
Oil Hardened 830° C Tempered 300° C for 20 mins.	415	34.0	14.4×10^6	7.1%	1.012"
Oil Hardened 830° C Tempered 350° for 20 mins.	382	34.0	14.4×10^6	6.5%	1.039"
Oil Hardened 830° C Tempered 450° C for 20 mins.	322	32.3	14.5×10^6	8.0%	.954"
Oil Hardened 830° C Tempered 500° C for 20 mins.	283	29.5	14.85×10^6	7.2%	.857"

detailed in the B.E.S.A. specifications 5004 and 4.K.6 for piston-ring pots. These specifications designate this as a tensile test and the formula given incorporates a factor for expressing the results in terms of tensile. This involves a constant of 1.6, which is low as compared with the figures of 1.8 and 2 looked upon as a more normal relation between transverse breaking strength and tensile. The result of the test have, therefore, been expressed as modulus of

rupture as being less open to objection than the tensile-strength equivalent.

The direct tensiles obtained on small test-bars cut from the same casting as used for ring tests are given in column 5 of Table II. It will be seen that not only are the direct tensile results in the same order as the modulus of rupture, but that the relationship of transverse strength = twice tensile, holds fairly closely in each case. The tests on tempered samples clearly show the improvements resulting from this operation as compared with the quenched samples. The tempered samples show little reduction in hardness, but the modulus of rupture and tensile strength which are definitely low on the samples hardened only recover on tempering to a figure in excess of the as-cast sample. There is a drop in the elastic value of both hardened and hardened and tempered samples. In this respect the writer's results do not quite confirm those given by Hurst,‡ the reason possibly being that the writer's tests were carried out in the manner prescribed in the B.E.S.A. specifications, while Hurst's results were carried out by applying the load in the opposite direction, and it is not certain that the same formula would hold.

The permanent set value in column 4 of Table II indicates that the hardened and tempered material deforms much less under load than in the as-cast condition. These tests are carried out by stressing test-rings as already described, to 14 tons per sq. in., calculated by the formula given for the tensile tests in B.E.S.A. specification. The figures given are the results of tests made on the first stressing as compared with the second stressing results given by Hurst. It might be inferred from the relatively high permanent set values obtained on hardened samples that this material is more ductile than the tempered samples. This is not borne out by experience, as the hardened material is invariably more brittle than after tempering. It would appear

‡ J. E. Hurst, *loc. cit.*

that the apparently high permanent set is due to the fact that in the case of the hardened material the stress at which the permanent set is measured (14 tons per sq. in.) is very near to the ultimate breaking strength of the material as compared with the as-cast and tempered samples. There would appear to be a little inconsistency in the results on sample 5.0/E65, where the Brinell hardness is shown as higher after tempering than on the sample hardened only. This is not generally the case, as will be seen from the results on sample 4.5/G85, which is typical of many other tests carried out. The reason for including 5.0/E65 was to include the "direct" tensile tests which were not carried out on other samples.

An attempt has been made to approximate the brittleness from the gap opening of the ring before fracture, but it would appear that the gap opening, depending as it does on the tensile strength, the elasticity of the material, and the permanent set, has no direct connection with brittleness.

In order to obtain definite evidence on this matter, tests have been carried out on the special repeated-impact testing machine illustrated in Fig. 5. This machine was constructed primarily for testing chilled-face cast-iron tappets. The tappet (of the mushroom-head type) is held in the chuck and subjected to four blows per revolution from the hardened steel hammer. The dead weight on the beam can be varied to suit designs of differing sections. Tests carried out on this machine have indicated a very definite increase in the number of blows required to fracture in the case of hardened and tempered material as compared with the same material as cast, irrespective of whether or not the face was chilled (as is normally the case with tappet heads). This conclusion has been amply confirmed by recent repeated impact tests on a Stanton machine.

The martensitic structure of hardened and tempered cast iron as compared with the pearlitic structure of the same material as cast

is shown in Figs. 6 and 7. As the tempering temperature increases, the martensite breaks down into troosite and sorbite, with reduction of hardness, and with a reduction in transverse

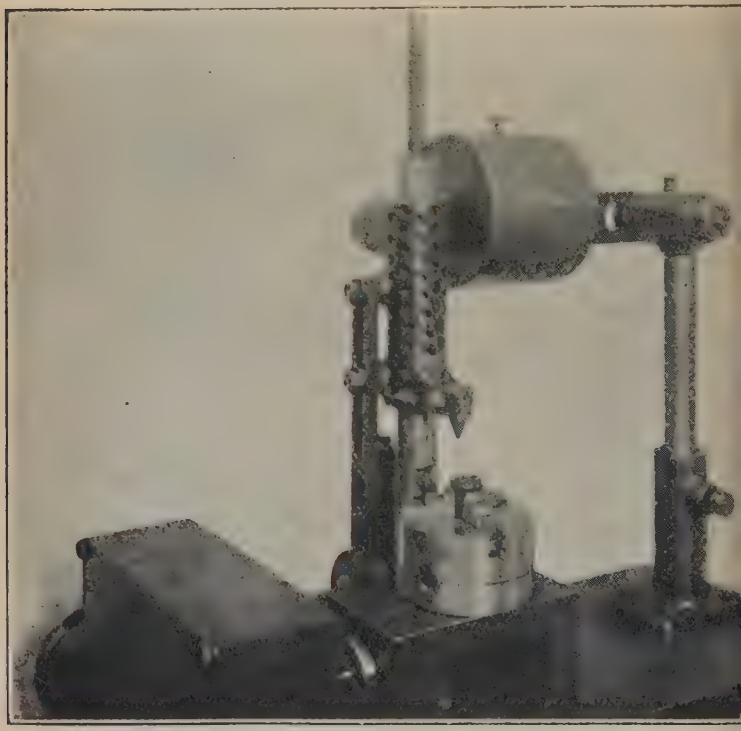


Fig. 5.—Repeated Impact Testing Machine.

strength, if the tempering temperature rises to more than 450 deg. C. (see Table II.)

Having outlined the chief developments which have taken place in recent years and principles underlying them, one or two examples of their application may be given.

Cylinder Liners.

Cylinder liners of either the wet or dry type, illustrated in Figs. 8 and 9, are in common use. Dry liners which enable a worn cylinder block to be readily brought back to standard, thus avoiding the necessity for oversize pistons

Fig. 6. — Centrifugally-cast Cylinder Liner. Etched Structure. × 1,000 dias.

and piston rings, were found to be the only logical way of dealing with the acute cylinder wear problem in commercial vehicle engines consequent on the increased severity of service conditions. From the point of view of facilitating subsequent renewal, some manufacturers fit dry liners in the original engine. Others rely on

obtaining a reasonable first life from the cylinder, leaving subsequent renewal to the user. Wet liners, while still retaining the feature of renewability, aim at avoiding any possibility of imperfect heat flow through the pressed-in dry liner to the cylinder block and water jacket.

FIG. 7.—CENTRIFUGALLY-CAST LINER IN THE HARDENED AND TEMPERED CONDITION. ETCHED STRUCTURE. × 1,000 DIAS.

They enable the cylinder block to be greatly simplified, and permit the use of cylinder blocks of light alloys, with consequent saving in weight.

It will be noticed that both wet and dry liners enable the cylinder bore to be of material specially designed to resist wear. Both lend themselves to hardening and tempering on the lines

already described. Some figures obtained from tests in commercial vehicles are given in Table III. These represent typical service results, the liners of different materials generally being fitted alternately in the same engine. Engine conditions vary so widely that it is unsafe to draw conclusions except from "side by side" tests. There are, however, unmistakable increases in mileage per 0.001-in. cylinder bore wear where cast-iron pistons are used and with hardened and

FIG. 8.—CENTRIFUGALLY-CAST "WET" LINER.

tempered liners as compared with unhardened liners or the original cylinders. Cylinder wear should always be expressed as miles run per 0.001-in. cylinder bore wear. Figures recently published* showing the depth of wear, *i.e.*, half the cylinder bore wear, may lead to confusion in comparing results.

Cylinder liners whether wet or dry are invariably made from centrifugal castings and do not normally contain more than small percentages of special elements such as nickel and chromium.

* FOUNDRY TRADE JOURNAL, October 29, 1931.

Unhardened, they usually have a Brinell hardness of approximately 220-240, while they may range from 400 to 500 in the hardened and tempered condition. For commercial vehicle fleets where mileages of 50,000 (roughly equal to a year's work) or even 80,000 miles before dismantling the engines ar aimed at, the use of hardened and tempered cylinder liners is almost a necessity.

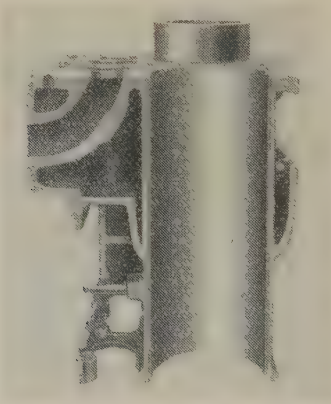


FIG. 9.—CENTRIFUGALLY-CAST "DRY" LINER.

Valve Seats.

The wear on valve seats in commercial vehicle engines is a problem of almost equal importance to cylinder wear. Inserts machined from centrifugal castings are widely adopted for renewing a worn seating. The special conditions of resistance to heat and resistance to the hammering of the valve call for special consideration of the material.

A composition similar to that given for the samples referred to in Table II, except that the nickel is 0.5-0.8 per cent. and chromium

0.5-0.8 per cent., appears to very satisfactory. This is used either in the normal condition or hardened and tempered to a Brinell of approximately 300 at which the actual valve

TABLE 111.

CYLINDER WEAR RESULTS.

The following results are expressed as the number of miles run per 0.001" of cylinder wear. Except where otherwise stated liners are Centrifugally cast..

		Type of Liner	Rings	Pistons	No. of Miles per .001" wear
A.1.	1.	Low Silicon with 1% nickel	Standard Cast Iron	Bi metal Aluminium Head.	2.440.
	2.	Special Iron (No Analysis given)	"		1.786.
	3.	1% nickel .3% Chromium.	"		2.277.
A.2.	1.	Standard Mixture	Standard Cast Iron	Bi-metal Aluminium Head	2.300.
	2.	Standard Mixture Hardened & Tempered	"		4.000.
B.	1.	Standard Mixture Hardened & Tempered	Standard Cast Iron	Aluminium	2.692
	2.	Standard Mixture Unhardened	"	Cast Iron	4.576.
	3.	Standard Mixture Hardened & Tempered	"	Cast Iron	5.601.
C.	1.	Standard Mixture Hardened & Tempered	Cast Iron Hardened and Tempered	Cast Iron	18.000.
	2.	Standard Mixture Hardened & Tempered			6.000.
D.	1.	Standard Mixture Hardened & Tempered	Standard Cast Iron.	Aluminium	5.222) 4.250.
	2.	Standard Mixture Hardened & Tempered			3.666)

seating may be machined after pressing the insert into the cylinder block. The use of austenitic cast iron which appears satisfactorily to resist heat has possibilities particularly in

aluminium cylinder blocks where the higher coefficient of expansion of austenitic cast iron as compared with ordinary iron is an advantage.

The results of some tests carried out to determine the reduction in hardness of hardened and tempered valve seat samples at various temperatures are shown in Fig. 10, Grade II being material of normal composition (nickel 0.5 per cent. and chromium 0.2 per cent.) and Grade I similar in composition except that the chromium was approximately 0.75 per cent. It will be

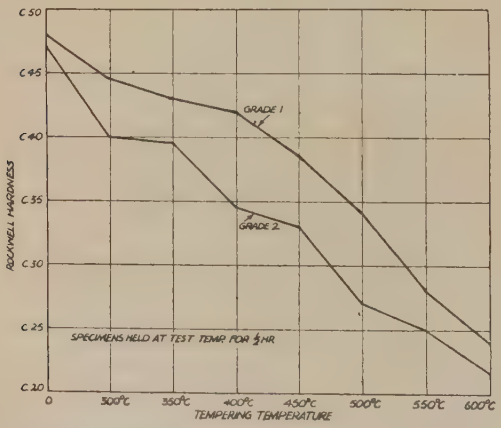


FIG. 10.—SHOWING DIMINUTION OF HARDNESS WITH INCREASING TEMPERATURE.

seen that although the samples had originally similar hardness values indicating that the chromium was not a necessity in securing the increase in hardness in heat-treatment it had the effect of rendering the hardened structure more stable under heat.

Valve Guides.

In recent years considerable trouble with valve stem and valve guide wear has been experienced coincident with the adoption of modern austenitic valves which are relatively soft compared with

the steels formerly used. Numerous cases have been found of the valve stem " picking up " on the valve guide, this, of course, being very pronounced if there is any appreciable side thrust on the valve stem. While in some cases the addition to the valve guides of nickel up to 1 per cent. and chromium up to 0.5 per cent. appears to effect an improvement, the use of hardened and tempered valve guides appears to be the most certain means of overcoming the difficulty. This confirms the theory that to secure a good wearing combination bearing metals should generally show a considerable difference in hardness, as for example hardened

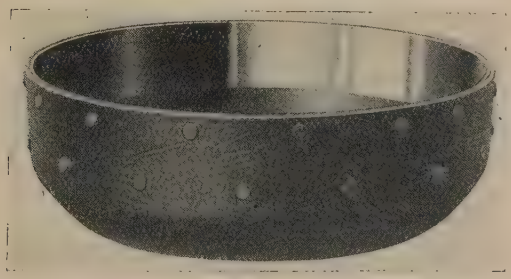


FIG. 11.—STEEL BRAKE DRUM FITTED WITH CENTRIFUGALLY-CAST LINER.

steel running in conjunction with phosphor bronze. An exception appears to be cast iron with cast iron which as-cast or hardened and tempered forms an excellent combination.

Brake Drums.

While it is agreed that cast iron is unquestionably the most efficient brake-drum lining material there is no general agreement as to the best method of application. For small drums a complete drum of special cast iron may be considered satisfactory. For larger drums, especially those used on commercial vehicles, a drum of steel or aluminium alloy with a cast-iron liner machined from a centrifugal casting is a more

satisfactory design. Where it is desired to use aluminium drums the aluminium may be cast round the liner, the latter being grooved to form keys which prevent the liner from rotating, or the liners may be of austenitic cast iron which

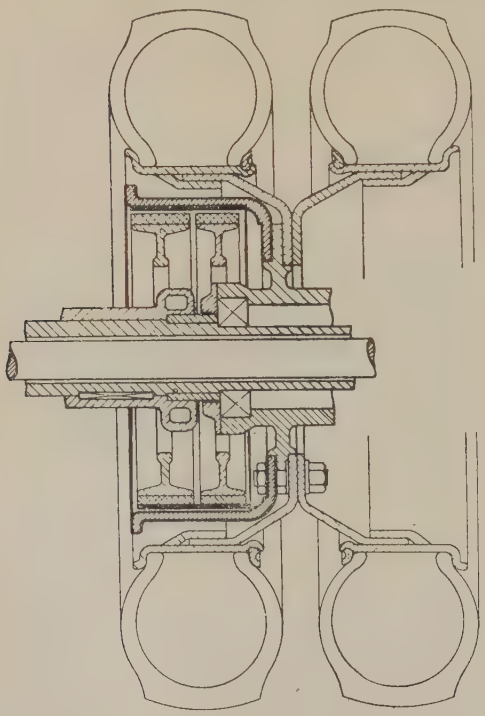


Fig. 12.—Steel Brake Drum with Cast-Iron Liner on a Commercial Vehicle.

will expand at a similar rate to the aluminium drum.

As a means of renewing worn steel drums the method of pressing in a liner of centrifugal cast iron is firmly established. The liners which

are machined about 0.010 in. to 0.015 in. greater on diameter than the bored out drum are riveted to the drum after pressing in, using, preferably, two rows of rivets about 3 to $3\frac{1}{2}$ in. pitch (see Fig. 11). The riveting is done purely as a "safety first" measure in the unlikely event of the interference fit being insufficient to prevent the liner rotating. Drums treated in this way show no signs of wear or surface cracking after 40,000 miles and there appears no reason why they should not give a life of up to 80,000 or 100,000 miles which is far in advance of that obtainable from most steel drums. With a lining of cast iron the brake shoe linings which, it is found, should not be of the wire-bonded type, give greatly improved life.

The drums may be fitted with liners in the first place, not so much from the point of view of facilitating renewal but to secure the best wearing material—in fact greatly to minimise the necessity for subsequent renewal. A composite construction—cast-iron liner in a steel drum—has a considerable advantage as regards lightness and consequent reduction of "unsprung weight" as compared with an all cast-iron drum.

In conclusion the author would express his thanks to the British Cast Iron Research Association for providing the figures on thermal conductivity (originally determined by Dr. J. W. Donaldson) and coefficients of expansion, also to Mr. W. A. Oubridge, M.I.Mech.E., managing director of The British Piston Ring Company, Limited, for permission to give this Paper.

DISCUSSION.

Mr. Hall, in seconding a vote of thanks proposed to the lecturer by Mr. Edwards, asked whether, if he were casting an alloy material, would he use a hematite base; he was a believer in the inherent or hereditary properties of cast iron. Further, was it necessary when alloying nickel and chromium to limit phosphorus to a low percentage? Mr. Hall mentioned, regarding alloy irons, that in analysing a number of cylinders recently, he found the chromium was only

0.1 per cent., which suggested a desire for obtaining a higher price rather than increased wear.

Inherent Properties and Alloying.

Mr. Twigger replied that the question of hematite versus refined irons brought up straight away a consideration of inherent properties. He believed there was probably something in the view that refined irons or high steel mixtures did not give the same results as regards resistance to wear as could be obtained with some of the more normal types of foundry irons. While the enormous increase in recent years in cylinder wear was due to some extent to the severity of modern conditions—higher speeds, higher pressures and so on—he was not sure that some of this wear was not aggravated by the use of high percentage steel mixtures. As to using a low-phosphorus base when adding nickel to chromium, he did not think those alloys made any difference to the most desirable phosphorus content. For most classes of work a much lower phosphorus was used to-day compared with a few years ago. Nickel or chromium produced their several effects, irrespective of the phosphorus content within the limits usually met with. With regard to the cylinder block of "chromium" iron, which contained only 0.1 per cent. chromium, it was not uncommon to find 0.1 per cent., or even more, in ordinary iron. In some cases where his firm desired a low chromium it came unexpectedly high, and they had found it advisable to start analysing quite ordinary types of iron, which often showed an appreciable percentage of chromium. Therefore it was possible that the particular cylinders referred to had no extra chromium added.

Alloy Additions and Shrinkage Stresses.

Mr. Edwards, remarking that nickel in conjunction with chromium was sometimes employed to render a complicated design less noxious, asked could Mr. Twigger suggest the percentages of those alloys necessary to prevent shrinkage stresses

in castings. He cited a case where the walls of a casting varied in thickness from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. and $\frac{3}{4}$ in. and these thicknesses were in close juxtaposition. If these shrinkage stresses could be overcome in such castings as ordinary designers sent to the foundry, both in steel and iron, then the industry would have arrived at a very satisfactory state of development. Many designers seemed to think a moulder could make anything, but they could not emphasise too much that foundries much preferred an even design and uniform sections than to dabble with an heterogeneous composition. He noticed there was some difference in the test results on tempered and untempered cast iron compared with the investigations of Mr. Hurst and asked would the fact of the pearlite structure replaced in the as-cast condition by the martensitic structure on hardening explain the difference in the strength. Regarding the wear of a riveted brake drum, it would be interesting to note what happened when a brake drum was in service without rivets. It was very interesting indeed to hear that cast iron had a considerably longer life than steel for this particular purpose.

Shrinkage Unaffected.

In reply Mr. Twigger said the element that would prevent shrinkage stresses in castings having divergent sections in juxtaposition did not appear to have so far been discovered. He did not think nickel and chromium made any difference to shrinkage stresses, which would always be present in uneven and irregular designs, but they did to some extent enable one to produce a denser casting with more even grain, thus keeping the thicker sections sound with the thin sections still machinable.

While there was some difference in elasticity values in the results obtained by Mr. Hurst and himself they agreed as to the drop in strength on hardening and recovery on tempering. He was not questioning Mr. Hurst's results in the least. The difference was probably accounted for by the difference in test procedure.

It was undoubtedly the replacement of the pearlitic structure by martensite together with probably troosite and sorbite in the tempered samples which accounted for the increase in hardness, and in the case of sufficiently tempered samples the increase in strength over the as-cast material as the graphitic carbon was not removed by the hardening process. On the score of safety first many people favoured securing the brake liners in the drums with rivets. They had both aluminium and steel drums with cast-iron liners secured solely by an interference fit which were shortly to undergo stringent tests.

Effect of Chromium.

Mr. Wright inquired was not the increased resistance to wear and heat in chromium iron due to the effect of chromium on the state of the carbon. In his foundry chromium had been used; not to any great extent, perhaps 0.3 per cent. or so, in irons containing 3.3 per cent. total carbon—the combined carbon being just under 1 per cent.—with normal sulphur and fairly low phosphorus. In a polished specimen magnified to quite a low degree, perhaps to 50 or 60 diameters, they found that the graphite appeared to be broken up into very thin flakes. This in itself might account for the special qualities of the iron as regards heat- and wear-resisting properties.

Improved Quality Ascribed to Close Grain and Finely Divided Graphite.

Mr. Twigger replied that generally chromium ensured a closer grain; it made for finely divided graphite flakes initially, which was no doubt an advantage as regards resistance to heat. Chromium also stabilised the carbide under heat, so that the pearlite decomposed less rapidly into ferrite and graphite.

Phosphorus Content and Wear.

Mr. Neath, alluding to the fairly high phosphorus content used in former years, now displaced in practice by a low percentage, asked how much the lower phosphorus in cylinder irons

was responsible for increased wear. He mentioned that there was quite a strong school of thought which considered phosphorus a valuable factor in improving the resistance of cast iron to wear owing to the hardness of the phosphide eutectic.

Mr. Twigger, without being dogmatic, said he was inclined to think that fairly high phosphorus was beneficial as regards wear resistance. He believed that it might not be altogether a question of the actual phosphorus content but of the nature of the charge and the conditions under which it was melted.

Nickel as an Ameliorative for Draws.

Mr. E. J. Lewis remarked, in regard to exhaust manifolds, that an addition of 1 to 1½ per cent. nickel overcame the tendency for bosses to draw where they joined the pipe section.

Mr. Twigger replied that there were many instances where porosity tended to occur in the thick portions of castings of differing sections. In replying to Mr. Edwards on the question of shrinkage stresses, he was naturally thinking of the actual stresses in the material. Some forms of porosity were undoubtedly shrinkage cavities; but, on the other hand, thick sections when drilled often showed a porous appearance due to the very open grain. Nickel and chromium certainly tended towards securing a closer and more uniform grain and assisted more regular shrinkage. They were not an infallible cure for porosity, neither were they always necessary. Much could usually be done by careful selection of mixture and close study of methods of running.

Cast-Iron Brake Drums.

Mr. W. J. Molineux, speaking of solid cast-iron brake drums, observed that the mileage figures of 40,000 and 80,000 quoted were higher than those of which he had experience. It was no doubt difficult to arrive at comparative figures, as much would depend on the type of vehicle. In the case of larger vehicles subject to heavy service conditions, he thought the

shoes had to be adjusted every so many hundred miles when using high-carbon steel drums. With cast-iron drums, the conditions were altogether altered, but it seemed difficult to believe that a mileage of 40,000 could be obtained before adjustment or attention was required. Solid cast-iron drums were in use on various large commercial vehicles, so there seemed little question that they were sufficiently strong.

Mr. Twigger said his mileage figures were based on actual experience of service. Some cast iron which had been inspected after 40,000 miles showed practically no wear, and the report was made that there was no reason why the life should not exceed 100,000 miles. He was quite aware that there were many large cast-iron drums in use. A big advantage of a composite brake drum using steel pressings or aluminium castings, with a cast-iron liner, was that it could be very considerably lighter than a solid cast-iron drum, and thus ensure a saving in unsprung weight. Regarding Mr. Molineux's remarks respecting the use of chromium and nickel, Mr. Twigger said the object of the nickel was mainly to minimise the chilling effect of the chromium without detracting too much from the advantages of chromium in heat resistance.

Mr. Molineux said he rather differed as to the chromium effect; he understood it made the surface liable to crack.

Result of Overloading.

Mr. Twigger remarked that he had seen two cases of ordinary cast iron in use, one as a complete drum and the other a brake-drum liner, where there was definite surface cracking. In the case of the drum, it had been tested out under brutal conditions. Definite decomposition occurred on the inside of the drum; the pearlite had broken down. Moreover, owing to the high temperature, the surface of the material had actually been made to flow under the heavy brake pressure. The surface cracking was undoubtedly connected with the breakdown of the structure under heat.

Lancashire Branch.

LOW TOTAL-CARBON CAST IRONS AND THEIR SERVICE TO FOUNDRYMEN.

By W. West (Member).

When the foundryman speaks of the greyness or whiteness of his iron, he refers more particularly to the graphitic-carbon content rather than the combined carbon, because the graphite is more apparent from the fracture than the carbide or metallic matrix, in which the combined carbon is contained. The sum of the contents of the two kinds of carbon is reported as the total-carbon content. The graphitic carbon is of importance not for itself alone but rather because it serves as an approximate inverse index of the combined-carbon content contained in the metallic matrix. In a given total-carbon content the more graphitic carbon there is, the less is the content of combined carbon. It is also a necessity for the production of a soft, easily-machined metal, and, further, it assists the foundry to obtain a cheap and readily-cast metal capable of being poured into intricately-designed shapes, a quality which improves by means of an increase of the total carbon.

In some cases, too, the generation of the graphite is useful to the foundry process, because, occurring as it does during and immediately after solidification, it causes a sudden expansion, which produces castings more accurately to the shape of the pattern. These benefits, however, are derived by the founding and machining processes only, but do not entirely contribute to the quality of the metal, as the greater the amount of free graphitic carbon present, so is the product weakened and embrittled. The source and measure of the valuable qualities, such as strength and solidity, arise from the content of combined carbon contained

in the cast iron. In this respect, steel provides an enlightening comparison, with the carbon content entirely in the combined condition, which gives increased strength to the metal without any weakening influence such as the presence of free graphite creates.

This gain is heavily paid for, however, as the lower carbon content implies a much less fusibility and a higher casting temperature; the lack, also, of any expansion of the metal, such as the presence of graphitic carbon would provide during solidification, leads to greater shrinkage and contraction in solidifying and cooling. It is around this point of shrinkage that the experiments given in this Paper have been carried out. It is apparent, therefore, that if maximum strength is the chief quality desired of a cast iron, then the characteristics of it should embrace at least the following three factors:—(1) The total-carbon content, hence the graphitic carbon, should be as small as is consistent with soundness and machinability of the metal; (2) the combined-carbon content must be as high as possible within the limits of machinability; and (3) the graphitic carbon, if separated in compact masses, will contribute very largely.

There are, therefore, available two outstanding factors connected with the use of low total-carbon cast irons:—(1) increased strength and (2) increased liquid shrinkage. The first of these is a decided advantage, for it has been abundantly proved that tensile strengths hitherto unheard of have been produced. It may be of interest, therefore, at this early stage to recapitulate the theories which have been given in time past and provide a partial explanation for the benefit derived in this direction. Present knowledge of the nature of alloys, whatever composition these may be, has been elucidated by a correct understanding of the behaviour of water solutions.

Salt in Water Analogy.

If one considers, in the first place, a simple solution of common salt in water, it is known

that at ordinary temperatures the amount of salt which will dissolve is of a fixed amount, *i.e.*, 23.6 per cent., and no prolongation of shaking will effect a greater solubility. Should the temperature of the solution, however, be increased, further quantities of salt are readily dissolved until, at the boiling point of the liquid, a further limit of solubility is reached. It is, therefore, understood, and has been proved, that for each definite temperature a definite weight of water dissolves a certain weight of salt. Now, if a boiling and saturated solution of salt be allowed to cool, then salt will continuously separate out as crystals until a temperature of − 22 deg. C. is reached, when the whole of the remaining liquid solidifies or freezes. The continuous separation of salt as the temperature falls, causes the liquid portion to become successively more dilute, and it had been found that at the point when the whole solidifies at − 22 deg. C., the liquid last to freeze contains 23.6 per cent. of salt—an amount which exactly coincides with that which will go into solution at ordinary temperature.

Pure water freezes to ice at 0 deg. C., but an addition of salt in any quantity up to 23.6 per cent has been found to depress or lower the freezing point *pro rata* to the amount added, until at the maximum amount which will go into solution at ordinary temperatures, *i.e.*, 23.6 per cent., the freezing point is lowered to the furthermost point of −22 deg. C. It will be seen that a solution of salt with a saturation of under 23.6 per cent., when the temperature of the solution is lowered below 0 deg. C., and cooling continued, ice crystals will separate and the remaining fluid portion becomes more and more concentrated until it contains 23.6 per cent. of salt when it solidifies at −22 deg. C. A solution, therefore, containing 23.6 per cent. of salt solidifies or freezes as an unchanged whole without separation of ice or salt as the temperature of the solution is cooled to a temperature of −22 deg. C. These three solutions which have been considered, have one common solidifying or freezing temperature, *i.e.*,

−22 deg. C. as shown in Fig. 1. To this point the dilute and concentrated solutions behave similarly in that both separate the excess of one or other constituent during cooling.

Thus the concentrated solution separates solid crystals of salt, and the dilute solution separates out solid water or ice until at the common freezing point of each has reached the same concentration, *i.e.*, 23.6 per cent. It is, therefore, apparent that the final liquid portion has a composition which is independent of the original composition, and thus finally solidifies and melts at a constant temperature. This point in the

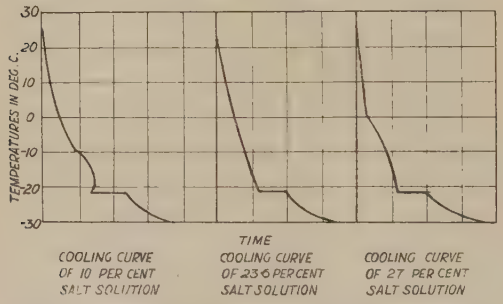


FIG. 1.—COOLING CURVE OF SALT SOLUTIONS.

case of metals is the eutectic composition or the cryohydrate point in water solution.

If cast iron be considered for the moment in the light of a carbon-iron alloy, and assuming that the other constituents usually present exert no influence, it becomes evident that the proportion of carbon which will dissolve in iron at different temperatures is a factor of importance. Just as water at boiling point is capable of dissolving the maximum amount of salt, which separates out on cooling, so iron at a high temperature will dissolve a large quantity of carbon which, on cooling, separates out in the form of plates of graphite. Iron at its melting point dissolves 4.3 per cent. of carbon to form a carbide, the presence of manganese

and chromium increases this solubility, while silicon, phosphorus, sulphur and aluminium diminish this power of solution of carbon in iron. Roughly speaking, carbon can exist in iron in two forms:—(1) that which separates out of solution as free graphite, and (2) that which is retained in combination with iron in the form of combined carbon.

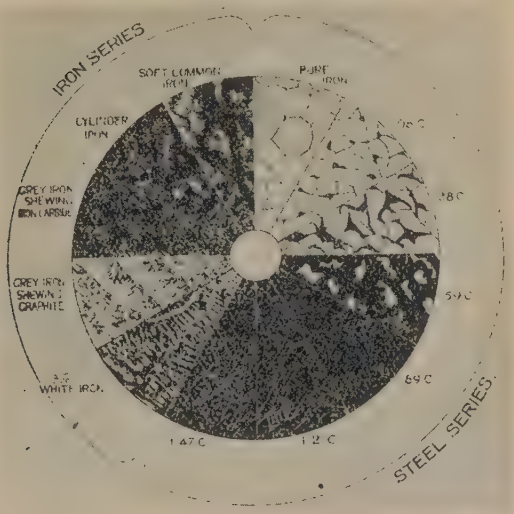


FIG. 2.—INFLUENCE OF CARBON ON IRON AS REVEALED BY THE MICROSCOPE.

If pure and solid iron were treated in contact with solid carbon by heating to a temperature between 900 deg. and 1,000 deg. C., it would be found that the carbon had penetrated the iron although neither be in the molten state. The carbon and iron had combined to form a carbide, and is an example of a solid solution of iron carbide in iron. Consideration of Fig. 2 will give some idea as to the effect of iron on the

structure by increasing the amounts of carbon. Increased carbon contents from 0.08 to 0.89 per cent. show a gradual decrease of the white areas of pure iron (ferrite), and an increase of dark areas of iron carbide (pearlite), until at 0.89 per cent. carbon, the whole mass is composed of iron carbide eutectoid, that is, a solid solution of iron carbide in iron. Further increase in the carbon contents produces a white network of glass-hard iron carbide (cementite) of a differing composition from iron carbide (pearlite), surrounding areas of iron carbide (pearlite).

Thus can the amount of carbon be increased until the iron will, when in the molten condition, take into liquid solution 4.3 per cent. carbon. Goerens, from his researches, therefore, concluded that carbon in molten iron is in solution as iron carbide, and that cast iron be considered strictly as a system of iron—iron carbide. This molten solution of 4.3 per cent. carbon in iron, when allowed to cool down, solidifies at approximately 1,135 deg. C., and is analogous to a 23.6 per cent. solution of salt in water which has a constant solidification temperature of − 22 deg. C., and is therefore known as the carbon eutectic. If an iron-carbon alloy contains less than this eutectic amount, say, 3 per cent., it will be found solidification takes place at a higher temperature, approximately 1,300 deg. C., and that as the metal cools down separation of iron (ferrite) would take place until the temperature reaches 1,135 deg. C., when the remaining liquid would have a eutectic composition of 4.3 per cent. carbon and would solidify as a whole. If a molten cast iron does absorb more carbon than the eutectic composition of 4.3 per cent., this is thrown out of solution as the molten iron cools down towards the solidifying point of 1,135 deg. C., in the form of graphite, and rises to the surface of the metal and is generally known as "kish."

So far only a pure iron-carbon alloy series has been considered, wherein 4.3 per cent. carbon in iron forms the eutectic composition, or, in other words, the alloy containing the lowest melting

point of the series. The addition of other elements modifies the carbon percentage at which the eutectic composition is formed. The presence of 1 per cent. silicon reduces the eutectic composition by approximately 0.3 per cent., and each 1 per cent. of phosphorus has a similar influence. So that an ordinary alloy containing 2 per cent. silicon and 1 per cent. phosphorus will be of eutectic composition when the carbon content is approximately 3.4 per cent. Molten cast iron as tapped from the cupola, therefore, during the process of cooling, first throws off in the form of kish, or primary graphite, any carbon it may hold in solution over and above that amount required to form the eutectic.

If, on the other hand, the amount of carbon is below that of the eutectic composition, pure iron (ferrite) is thrown out of solution until the concentrated liquid has this eutectic composition. The eutectic then freezes or solidifies and splits up, depending upon the rate of cooling and the percentage of silicon present, into free secondary graphite and combined carbon; this separation begins at 900 deg. C. and is complete at 700 deg. C. If molten iron is, therefore, chilled suddenly, so that the carbide eutectic cannot dissociate into graphite and combined carbon, hard castings will result owing to a high percentage of the latter. On the other hand, slow cooling leads to more complete separation of the carbon as graphite, and hence softer the iron.

Low Total Carbon in Relation to Combined Carbon.

The rate of cooling and the composition of the iron are two main factors which exercise the greatest influence upon the quality of the iron. Among all the constituents of the composition, the graphitic carbon heavily predominates. The development of the combined-carbon matrix has been largely fostered during the last few years, so as to obtain one composed largely of soft iron (ferrite) for ductility or of pearlitic structure for strength. Thus there arrives the introduction of low-carbon irons, and Jungbluth, in a

review of high-quality cast iron,[1] indicates that all the irons giving tensile results of over 20 tons per sq. in., have less than 3 per cent. total carbon, with the exception of irons superheated in the electric furnace, or jolted when molten.

Norbury and Morgan[2] state that in relation to normal graphite-structure cast irons, the tensile strength increases as the total-carbon content decreases and as the distance below the eutectic composition increases. For normal graphite-pearlitic irons, the strength at the eutectic composition is about 10 tons per sq. in. and increases up to 24 tons per sq. in., as the total carbon decreases to 3 per cent. and the silicon to 1.5 per cent. Still higher strengths are obtainable with normal graphite irons containing about 2.4 per cent. total carbon and 2 per cent. silicon.

Low Total Carbon in Relation to the Silicon Content.

For a long time it has been recognised that the size and distribution of the graphitic carbon has a very deciding influence upon the tensile strength. Anderson and Bessmen[3] give the results of their experiments, which show that, as the total carbon is lowered with a constant content of silicon and other constituents, the tensile strength is increased considerably. In each set of experiments they show that the combined carbon increases and the graphitic carbon decreases as the total-carbon content is lowered in relation to a constant silicon content. On the other hand, a high silicon content as well as a high total-carbon content, favours the rapidity of carbide decomposition resulting in larger graphite flakes and lower tensile strength. That silicon and carbon contents supplement each other in the production of cast iron exhibiting high-strength figures, is effectively shown by Klingenstein.[4]

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1 B.C.I.R.A. "Bulletin," No. 22.
2 J.I.S.I., May, 1930.
3 A.F.A. "Transactions," Vol. 36, 1928.
4 "Die Giesserei," February, 1926.

Further examples of this relationship between these two constituents are seen in the Lanz and Thyssen-Emmel processes. The former process operates with a total carbon of 3.25 per cent. and a low-silicon content of 0.7 to 1.0 per cent., and depends upon the preheating of the mould into which the metal is cast to retard the cooling to such an extent as to produce an all-pearlitic iron. The Thyssen-Emmel process makes use of a lower total carbon, 2.4 to 2.8 per cent., with a higher silicon content of 1.8 to 2.3 per cent., and attains the same object without any such heating of the mould. A low silicon content, as in the Lanz process, retards the rate of carbide disintegration, which necessitates the prolongation of the setting period of the iron, by preheating the moulds to differing degrees of temperature, according to the thickness of the section.

Where the total-carbon content is reduced, as in the Emmel process, the iron carbide is in a much more stable condition and, therefore, permits of the use of a higher silicon content which, when added in quantities suited to the rates of cooling under ordinary conditions in the foundry, results in an appreciable improvement in the physical properties of the resulting cast iron. The influence of superheating cast iron and its relation to the size of the graphite flakes, has been developed by Piwowarsky. He found that by increasing the temperature of the molten bath to 1,500 deg. C. the graphite content is reduced, the combined carbon increased and the residual graphitic carbon which separates on cooling is in a much finer state of subdivision. These results from superheating are shown to give increased strength to the resulting cast iron. Hanemann explains this phenomenon by the "germ" theory, whereby the superheating destroys or takes into solution to a greater degree nuclei of graphite flakes, which, under ordinary conditions of melting, remain suspended in the liquid iron and provide the starting point for a coarse- crystallisation of the graphite, which separates from the dissociated iron carbide during the cooling period.

Relation between Low Total-Carbon Content and Liquid Shrinkage.

Where high-strength figures are the main point, it is apparent that the preceding consideration of low total carbon in relation to the structure is of paramount importance. It is, however, possible to carry out the search too far at the expense of foundry economics. There is a popular belief that shrinkage and contraction effects are due to silicon content, but the following experiments show that this is not so.

In a search for high-strength and all-pearlitic iron capable of the maximum resistance to wear in automobile cylinders, the total-carbon content

FIG. 3.—SINK EFFECT ON A 6-CYLINDER BLOCK.

of one day's run was purposely decreased from 3.3 to 2.9 per cent. in an attempt to effect a finer state of graphitic carbon. Substantially, the silicon content and amounts of other constituents remained the same, and the temperature of casting approximated 1,350 deg. C. This temperature cannot be considered as a superheat in any way, and so was not responsible for the unexpected result. With every casting there occurred a well-defined depression at every juncture where a change of section occurred. Fracture of the castings through the declevities showed a very close-grained and sound section, as shown in Fig. 3, which illustrates the positions of these liquid shrinkages on a six-cylinder block and, Fig. 4, on a small oil-pump body,

these serving only as two types of many other castings in which the trouble occurred.

A search among published research work brought to light Smalley's few experiments on "The Influence of Carbon upon Volume Changes of Solidification."[5] No conclusions, however, can be drawn, as the information given is insufficient. It is at once apparent from the appearance of the declevities and the soundness of the fractured sections that the trouble is not the same as the usual shrinkage cavities, such as is shown in Fig. 5, which are common within

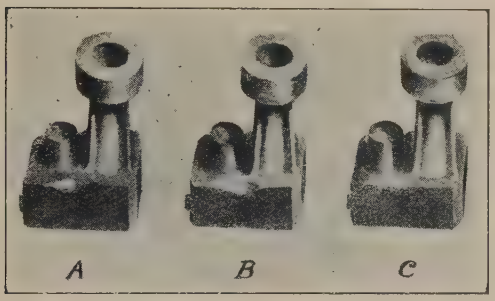

FIG. 4.—OIL-PUMP BODY. THE MICROS OF A, B AND C ARE SHOWN IN FIGS. 6, 7 AND 8.

thick sections of metal where the skin is perfectly flat, and the cavity is only revealed upon drilling or machining into the part.

Two queries arise as to the cause of the shrinkage and to its elimination:—(1) Is it a direct effect of the low total-carbon content and (2) can it be eliminated by a reduction or increase in the silicon content or by superheating the molten iron? The following experiments have been carried out, but the work is being continued, so a short summary of the results will only be given at present.

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5 I.B.F. "Proceedings," Vol. 16, 1922-23.

The experimental work has been planned in the following order:—

Cupola Cast Irons.

Series A.—Silicon content constant with variable total carbon; and Series B.—Constant total-carbon content with varying silicon content.

Crucible Cast and Superheated Irons.

Series C.—To compare with Series A; Series D.—To compare with Series B; and Series E.—Lower total carbon than previously used with varying silicon contents.

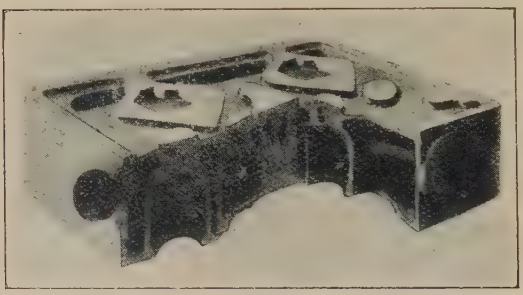

Fig. 5.—A Type of Shrinkage Cavity common in thick Sections of Metal.

Cupola Cast Irons.

Series A.

Table I shows a set of six separate casts, throughout which the silicon content has been kept as near a constant as possible within the working of a baby cupola, with an increasing total-carbon content ranging from A1 at 2.75 per cent. to A5 at 3.7 per cent. in quarter percentages. The "baby" cupola through which the metal was melted is of the usual design, and capable of melting approximately 5 cwts. of cast iron per hour. For experimental purposes, a type of casting, *i.e.*, an oil-pump casting, was chosen as a standard sample in which to show

TABLE I.—*Experiments on Liquid Shrinkage.* Series A.

TOTAL CARBON *v.* SILICON.

Temperature of casting 1,350 deg. C.

	Si Per cent.	T.C. Per cent.	C.C. Per cent.	M.S. Tons per sq. in.	Tr'nsv'rse in cwts.*	Type of sink.	Fracture.
A1	1.86	2.75	0.94	21.4	32.8	Deep	Solid close grained.
A2	1.78	2.91	0.91	18.0	28.4	Deep	,, ,,
A3	1.78	3.24	0.67	16.0	Mis-run	Shallow	,, ,,
A4	1.60	3.51	0.63	14.8	28.0	Nil	Open grain and spongy in section.
A5	1.90	3.70	0.63	13.0	33.0	Nil	Open grain and drawn in section.

N.B.—The balance of the composition was approximately Mn, 0.80 per cent.; S, 0.06 per cent.; P, 0.40 per cent.

* Test-bar, 1 in. × 1 in. × 12 in.

any variation in the liquid shrinking effect with an alteration of the mixture.

Whilst it was thought that the use of "Keep's" shrinkage test would give more accurate and technical information, which is indubitable, it was decided that a more practical view should be taken, for time did not permit of an extension of the experiments on the one hand, and on the other, to practical minds as those of foundrymen, it was deemed rather more satisfactory to express the results as visual observa-

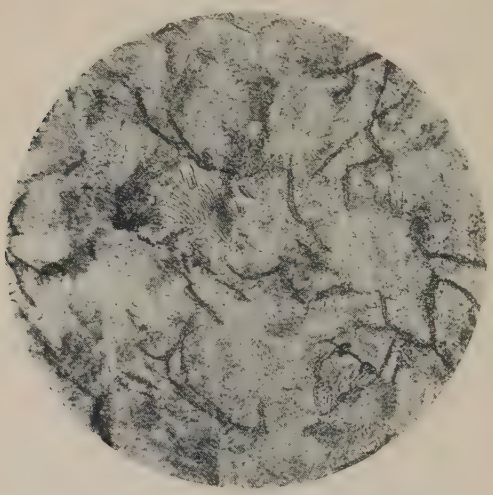

Fig. 6.—Microstructure of A, Fig. 4.

tions than as graphs and figures. The oil-pump casting is of ideal design, through its grossly unequal sections, to produce the maximum of shrinkage. Made in oil-sand mould, conditions of casting from this point of view were standard, and the method of running down the stem through a cup runner having one small ingate was adopted all through.

Tensile test samples, 1 in. by 1 in. by 9 in. and transverse 12 in. by 1 in. by 1 in. bars were

cast in the upright position and made in oil-sand moulds. All tests were made in duplicate on 0.798 in. test-bars, and no great variation in any of the two bars of each set was observed, except where blow holes occurred.

Remarks on Series A.

The tensile strength of each cast decreases with increasing total carbon, which is what can be expected, but the transverse tests do not

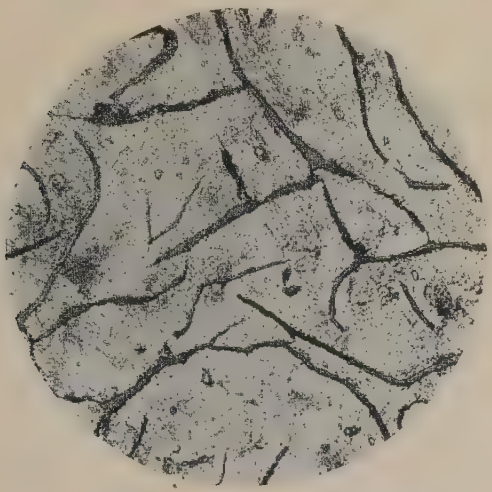

FIG. 7.—MICROSTRUCTURE OF B, FIG. 4.

fall in the same ratio, this can only be accounted for by the usual fickleness of this test. The liquid shrinkage took place very pronouncedly on the top of the heavy flat section of the casting in the first three casts, and when the total carbon had exceeded 3.24 per cent a marked difference was observed, the phenomenon entirely disappearing with a content of 3.51 per cent. Experience has proved beyond doubt that the critical period for the occurrence of this liquid shrinkage commences when the total carbon falls

to 3.24 per cent. with an increasing marked degree as the content falls below this figure.

Remarks on Series B.

An increase in the silicon content with the total carbon in this series constant causes a similar decrease in the combined carbon as in Series A, where the silicon content is the constant and the total carbon the variable. The sink effect, however, remains unchanged through-

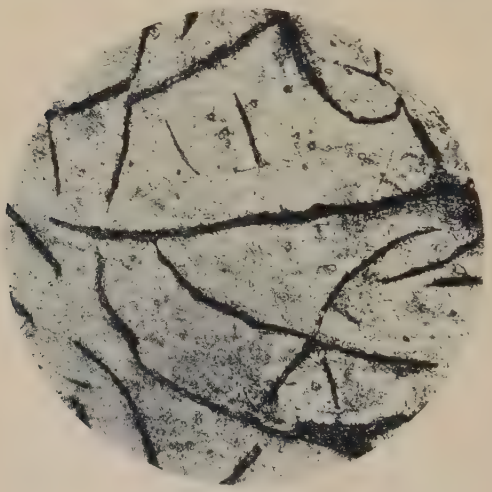

FIG. 8.—MICROSTRUCTURE OF C, FIG. 4.

out the series and clearly showing that an increase in silicon within the practical range of the series has no effect.

Turner[6] points out that a cast iron having a solidifying point of 1,150 deg. C. on passing down through the cooling range first expands and then contracts, it then expands again and continues to contract. At the first expansion the coarse-grained graphite carbon begins to be

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TABLE II.—*Experiments on Liquid Shrinkage.* Series B.
SILICON *v.* TOTAL CARBON.
Casting temperature 1,350 deg. C.

	Si Per cent.	T.C. Per cent.	C.C. Per cent.	M.S. Tons per sq. in.	Tr'nsv'rse in cwts.*	Type of sink.	Fracture.
B1	1.66	2.75	0.99	18.8	35.0	Deep	Solid close grained.
B2	1.86	2.75	0.94	20.0	32.8	,, ...	,, ,,
B3	1.96	2.75	0.75	19.2	31.0	,, ...	,, ,,
B4	2.12	2.71	0.92	Mis-run	Mis-run	,, ...	,, ,,
B5	2.32	2.75	0.85	17.6	Mis-run	,, ...	,, ,,
B6	2.84	2.60	0.85	16.6	33.0	,, ...	,, ,,
B7	2.88	2.53	0.73	17.0	32.0	,, ...	,, ,,
B8	3.12	2.56	0.90	18.24	33.2	,, ...	,, ,,
B9	3.62	2.55	0.61	18.6	35.0	Deep and localised, drawn in centre.	,, ,,

N.B.—The balance of the composition was approximately Mn, 0.80 per cent.; S, 0.06 per cent.; and P, 0.40 per cent.

* Test-bar, 1 in. × 1 in. × 12 in.

separated and continues to do so. At the next stage, somewhere about 900 deg. C., a fair amount of fine-grained graphite is separated and continues to do so, until at 700 deg. C. this action is complete. It was thought possible that by superheating the metal some alteration might be made in the order of the separation of graphite and hence the shrinkage, expansion and contraction, and that if this were so, it might have some effect upon the liquid shrinkage under observation. Series C was, therefore, carried out at a casting temperature of 1,450 deg. C., using the same mixtures and similar material to that used in Series A. The metal in this case was melted in a 200-lb. crucible pot in a forced-draft coke fire by means of which a high temperature was obtained.

Remarks on Series C.

The higher temperature of casting has caused the fracture of the higher total-carbon specimens to be very much darker than the corresponding cupola-melted casts—this phenomenon is quite marked. Microscopical examination of all the specimens will be made at a later date and incorporated in a further Paper. Superheating has made a marked improvement in the transverse tests obtained in this series, as compared with those given in Series A. This can be explained by the finer distribution of graphitic carbon resulting from the superheating, as is evidenced in the darker colour of the fractures.

Liquid shrinking diminishes with a content of total carbon of 3.30 per cent., which coincides with the results obtained in Series A, there is not the coarsening of the grain in the centre of the sections as the content of total carbon increases—this phenomenon is characteristic of Series A. Comparative figures were now sought with Series B, where the total carbon was kept constant and the silicon percentage varied; in this case the metal was melted in a crucible pot also and the temperature raised to 1,450 deg. C. A shortened series of casts can only be reported, as some of the lower silicon-content experiments

TABLE III.—*Experiments on Shrinkage.* Series C.

TOTAL CARBON *v.* SILICON.

Crucible melted and cast at 1,450 deg. C.

	T.C. Per cent.	Si Per cent.	C.C. Per cent.	M.S. Tons per sq. in.	Tr'nsv'rse in cwts.*	Type of sink.	Fracture.
C16	2.67	2.5	0.52	21.4	35.0	Sunk & drawn	Close grain, light grey.
C17	3.16	1.92	0.45	17.1	34.0	Sunk ..	,, ,,
C21	3.30	2.00	0.86	16.0	28.0	Slightly sunk	,, ,,
C18	3.43	2.00	0.42	18.3	32.0	Nil	Close grain, dark grey.
C19	3.57	1.92	0.68	15.8	27.0	Nil	,, ,,
C20	3.86	2.00	0.50	16.8	28.0	Nil	,, ,,

N.B.—Balance of the composition was approximately Mn, 0.80 per cent.; S. 0.06 per cent.; and P, 0.40 per cent.

* Test-bar, 1 in. × 1 in. × 12 in.

TABLE IV.—*Experiments on Shrinkage.* Series D.

SILICON *v.* TOTAL CARBON.

Crucible melted and cast at 1,450 deg. C.

	Si Per cent.	C.C. Per cent.	T.C. Per cent.	M.S. Tons per sq. in.	Tr'nsv'rse in cwts.*	Type of sink.	Fracture.
C25	2.36	0.83	2.60	15.3	32.0	Deep	Close grain, light grey.
C26	3.06	0.79	2.60	15.8	29.0	Deep & drawn in section	,, ,,
C27	4.30	0.70	2.50	14.9	28.0	Deep & drawn in section	,, ,,

N.B.—The balance of the composition was approximately Mn, 0.80 per cent.; S, 0.06 per cent.; and P, 0.40 per cent.

* Test-bar, 1 in. × 1 in. × 12 in.

came out with erratic total-carbon percentages, and were not reliable comparisons.

Remarks on Series D.

The tensile results from this series are very much lower than those obtained from cupola-melted casts of Series B, when comparing those of similar chemical composition. The transverse specimens suffer in the same way. The series is limited in its scope, so that an indication only can be taken from the results, but as far as these have been taken an increase in the silicon content has had little or no effect upon the liquid shrinkage under conditions of superheating.

Remarks on Series E.

It was quite by accident that this series of casts was made, owing to a loss in the total carbon during crucible melting being greater than that anticipated. The results show a fixed total carbon lower than any of the previous series with varying increases of silicon content. The molten metal was in each case superheated to a temperature of 1,450 deg. C. and the usual procedure followed.

Sinking in the thick section occurred with this series, accompanied by severe tearing of the metal during solidification; this was particularly marked in the castings where the silicon content was higher than 3.34 per cent. As might be expected, the tensile test and transverse results are exceptionally good throughout the series.

Types of Iron Used in the Experiments.

Series A.

A1 contained 50 per cent. pig-iron and 50 per cent. steel, previously melted and cast before use; A2 was made from 75 per cent. pig-iron and 25 per cent. steel, the steel being added in the form of remelted iron; A3, as No. 2; A4 contained 84 per cent. cold-blast pig-iron, and 16 per cent. plate steel added to the cupola, and A5 was from 100 per cent. pig-iron.

Series B.

B1 contained 75 per cent. pig-iron and 25 per cent. steel, the steel being added in the form of

TABLE V.—*Experiments on Shrinkage.* Series B.

SILICON *v.* TOTAL CARBON.

Crucible melted and cast at 1,450 deg. C.

	Si Per cent.	C.C. Per cent.	T.C. Per cent.	M.S. Tons per sq. in.	Tr'nsv'rse in cwts.*	Type of sink.	Fracture.
C1	1.86	1.32	2.15	—	38.0	Sunk & drawn	Close grain and light grey.
C2	2.16	1.06	1.90	21.2	38.5	,, ,,	,, ,, ,,
C3	2.30	0.93	2.01	21.4	39.5	,, ,,	,, ,, ,,
C14	3.04	0.73	1.99	16.8	35.0	,, ,,	,, ,, ,,
C4	3.34	0.85	1.90	18.9	36.0	,, ,,	,, ,, ,,
C8	4.30	0.80	1.91	17.8	34.0	,, ,,	,, ,, ,,
C6	4.70	0.58	1.94	18.4	30.0	,, ,,	,, ,, ,,
C7	5.42	0.41	1.94	16.4	25.0	,, ,,	,, ,, ,,

N.B.—The balance of the composition was approximately Mn, 0.80 per cent.; S, 0.46 per cent.; and P, 0.40 per cent.

* Test-bar, 1 in. × 1 in. × 12 in.

synthetic pig-iron; B2 was made from 100 per cent. synthetic pig-iron—50 per cent. pig-iron and 50 per cent. steel; B3, as B2, but correction of silicon was made by an addition of ferro-silicon in the furnace; B4, B5, B6, B7, B8 and B9, as B3.

Series C.

C16 contained 100 per cent. synthetic pig-iron —50 per cent. pig-iron and 50 per cent. steel—ferro-silicon being added to furnace for silicon correction; C17 was made from 70 per cent. pig-iron and 30 per cent. steel, the steel being added in form of synthetic pig-iron; C21 was 100 per cent. cold-blast pig-iron; C18 contained 80 per cent. pig-iron and 20 per cent. steel, the steel being added in form of synthetic pig-iron; C19 was made from 90 per cent. pig-iron and 10 per cent. steel, the steel being added in the form of synthetic pig-iron, and C20 was 100 per cent. pig-iron.

Series D.

C25 contained 70 per cent. pig-iron and 30 per cent. steel, the steel being added in the form of synthetic pig-iron, and the silicon correction was made in the furnace; C26 and C27 were the same as C25.

Series E.

C1 was 100 per cent. synthetic iron containing 50 per cent. steel addition; C2 was the same as C1, but with ferro-silicon correction through the furnace; C3, C14, C4, C8, C6 and C7 were the same as C2.

Conclusions.

The innumerable combinations which can be obtained from the number of constituents of cast iron give some idea as to the complex nature of this alloy. The phase-rule, however, shows that during the cooling of any one mixture, only one substance can separate out at one time. Keep has shown in his experiments that, in addition to two expansions which occur

during the solidification of cast iron due to the separation of primary and secondary graphite, a third expansion occurs with phosphoric irons when the phosphide eutectic is formed.

It follows, therefore, that the coarser the graphite or higher the total-carbon content, especially when accompanied by a corresponding silicon or phosphorus content, the greater the expansion which will occur during solidification of the metal. Contrariwise, the lower the total-carbon content, so is the range of solidification reduced, owing to the higher point of temperature at which it occurs.

Osann[7] states that piping or sinking does not occur if the alloy is of eutectic composition. Where a low total-carbon content of under 3 per cent. is employed, an increase in the silicon content, he suggests, will bring the iron to a state of eutectic, and one may expect therefrom little or no piping. The results, however, from the foregoing experiments where the total carbon is kept constant and the silicon successively increased, does not bear out his assumption.

In the face of the results obtained by these experiments, it would appear that liquid shrinkage is only prevented by having the requisite amount of total carbon present to counteract it by its own expansion during solidification. The alternative is to make provision on the casting for risers of sufficient capacity to feed over sections where such liquid shrinkage is likely to occur.

The use of low total-carbon irons to the foundryman is, therefore, seriously discountenanced by the difficulties encountered in foundry practice. Where high-test irons are a necessity, then the advantages gained outweigh other foundry disadvantages. It may be, however, that the low total-carbon cast irons will provide some valuable assistance to the increase of resistance to wear in automobile cylinders, and it is for this line of investigation that the above experiments primarily have been made.

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DISCUSSION.

Fluidity and Composition.

Mr. S. E. Dawson, opening the discussion, asked whether Mr. West had found that in the low total-carbon cast irons segregation of sulphur and phosphorus was checked or minimised. His own experience was that segregation had definitely been prevented, with rather better results in strength and machining property. That was what one would expect in view of the shorter period of the formation of the eutectic. Could Mr. West tell them anything about the total carbon and silicon in relation to fluidity? On the question of the germ theory, or inoculation theory as it might be termed, the temperature tests, if Mr. West took them, would be very interesting. He thought there was no question that in the low total-carbon irons the effect of the temperature was important to help to remove shrinkage troubles.

Mr. West said that he had pointed out that the sulphur was down to between 0.04 and 0.06 per cent. and the phosphorus ran from 0.2 to 0.4 per cent. Microscopical examination had not been made as yet on all the samples, but they were hoping to continue their investigations, and reap the benefit of the experiments which had been done, so at the moment he was unable to speak with any authority regarding the segregation of sulphur and phosphorus with low total-carbon contents. Off-hand he would say that if they had higher phosphorus and sulphur contents, the segregation of these would be more evenly distributed by reason of the shorter freezing range. With regard to the total carbon and silicon, they had not taken any tests like those Mr. Dawson apparently had in mind. He had purposely kept pure theoretical matters out of the lecture, because he thought foundrymen could visualise things better, or appreciate things better, by seeing the actual things instead of troubling with curves and graphs. Shrinkage

determinations were being collated from these experiments.

The Germ Theory.

Regarding the germ theory, the members would notice that, in some of the fractures, superheating to 1,450 deg. C. had produced a blackening of the fracture due to the carbon being more finely distributed throughout the iron. It had to be borne in mind, however, that the germ theory provided for the addition of calcium silicide, or some similar agent, to the molten metal at a certain period, in order to precipitate from a super-saturated metal the excess carbon. In view of this fact the high-temperature melts were not strictly in accordance with the provisions of the germ theory. Therefore, he could not, in any detail, give definite information, one way or the other, as to the reaction obtained by using the "germ theory." He could only emphasise that the experimental melts in the crucible had not shown any diminution of the liquid-shrinkage effect over the cupola-melted metal. He could not, therefore, agree that superheating was any material help in the removal of the trouble unless an alteration to the total-carbon content was also made.

Influence of Manganese.

Mr. J. A. Reynolds asked whether Mr. West, in his experimental work, had tried the effect of manganese. They knew that manganese, outside certain limits, gave a spiky fracture which was detrimental to wear resistance. Did Mr. West control it, vary it or ignore it?

Mr. West said their usual practice was to have 0.8 to 0.9 per cent. manganese in the final mixture. He was of the opinion that manganese did help to increase the resistance to wear of cast iron. It was similar in its action to a chromium addition, inasmuch as a definite carbide was formed. An increase of manganese to 1.5 to 2.0 per cent. would not be detrimental, providing the other elements in the mixture were made suitable for machining purposes. It

was hardly possible, in view of its influence, to ignore this element, and every attempt was made to control the content as far as possible.

Mr. A. Brierley said that he had never been able to obtain Mr. West's figure of 2.55 total carbon. Even when melting all steel in the cupola the total carbon ran over 3 per cent. By careful working they at times got down to about 3 per cent., but with ordinary cast iron the 2.55 per cent. was remarkably low. If he read the slides right, it was cupola-melted metal and not crucible-melted. A point had been raised about high-manganese content. He thought it would only increase the difficulty in making the particular cylinder block which was put on the screen. The high-manganese irons usually shrank a good deal more than a low-manganese iron. In that connection, Mr. Dawson's remarks about the temperature of casting helping to remove shrinkage trouble were very applicable. Possibly an increase in the casting temperature would result in a sounder casting. In relation to the resistance to wear of cast iron, had Mr. West considered what the effect would be of a small increase of phosphorus over the 0.4 per cent. mentioned? Phosphide of iron was very hard, and, as far as resistance to wear went, he thought a slight increase of phosphorus would be an advantage, provided it did not weaken the iron so much that it would not stand the high-service temperatures.

Carbon Pick-up during Melting.

Mr. West said he had omitted to mention that his cupola experiments were carried out in a baby cupola producing 20 cwts. of iron per hr. They aimed at 2.75 per cent. carbon and obtained 2.55 per cent. It was produced by using a 100 per cent. synthetic iron made in the electric furnace, having an analysis of 2 per cent. total carbon and 2 per cent. silicon. The 0.5 per cent. was picked up through the small baby cupola; in a large cupola they were never able to get above 2.9 per cent., when using steel alone. Regarding manganese and shrinkage,

from the fact that manganese formed a carbide, it might be theoretically assumed that it would accentuate the shrinkage effect, but he had not carried out any experiments in this direction. He did not know what Mr. Brierley meant by "high manganese." Personally, he should not call 1.2 per cent. high. If that was what Mr. Brierly had in mind, he would say at once that it had no marked effect of increasing liquid shrinkage. Higher casting temperature did not do away with liquid shrinkage. From the crucible they obtained 1,450 deg. C. pouring temperature, and for the benefit of the members he had brought a number of actual specimens; there were other types of casting, but these were most handy in form to bring along to show the effect of the pouring temperature of 1,450 deg. C. The increase of temperature to 1,450 deg. C. had had no effect whatever on the shrinkage.

He had quite an open mind on the matter of phosphorus in relation to wear. They themselves ran with 0.8 to 0.9 per cent. phosphorus for quite a long time. But before it could be definitely stated that phosphorus helped resistance to wear or *vice versa*, a multitude of experiments must be made, and one had to wait months before any practical result was obtained.

Silicon Variations.

Mr. A. Jackson remarked that he was glad Mr. West had not used difficult phrases to the complication of the subject; some experts were difficult to follow by those they were supposed to instruct. Mr. West would do a great deal to help the men in the foundry if he kept on the lines of the present lecture, thus enlightening the men who were not metallurgists. One thing about the graph thrown on the screen showing the silicon and carbon appealed to him as being very interesting. The line for the silicon was lowest on Monday morning, but rose gradually until Friday night. Then on Saturday morning it dropped. What appeared to happen in a foundry was that the furnace started from cold on Monday morning, and gradually as it warmed up they got

better results. It was a curious fact that they seemed to get the best iron on the Friday afternoon; Saturday was a short morning, and taking only the morning blow, they probably did not get the same temperature. Of course, if the temperature were raised, more silicon remained in the iron, sulphur passing out in the slag. In a cold melt the tendency was for a rise in sulphur and loss in silicon. These two points seemed to be strikingly illustrated in the graph.

Years ago, in a casting which ought to have been perfect on the underside, he observed a draw there. There was a depression almost as if a thumb had been pressed into the casting. That seemed to be a shrinkage, but there was something that was not consistent with the ordinary idea of shrinkage. They were told that instead of putting facing sand underneath the pattern they ought to use ordinary black sand. It was insisted that that was what they ought to do, and they did it. A quicker way and just as safe was to increase the depth of facing sand. It would appear in the first case that the black sand allowed air to escape from the mould freely; and in the other case the extra red sand or the facing sand stopped the air from going through to some extent, but did not cause the air to work back into the mould.

Mr. West, in replying, asked to be shown the graph to which Mr. Jackson referred. He then pointed out that the figures varied so little from day to day that it could be hardly said that they increased to any appreciable extent by the end of the week. If better iron was produced at the end than at the beginning of the week the obvious explanation is a lack of efficient control. Good and hot metal all the time was imperative, if satisfactory castings were to be produced. Silicon variation occurred more often than not through an indifferent quality of the scrap used in the cupola mixtures. Sulphur did not present any difficulty to the foundrymen when the manganese content was sufficiently large to take care of it. The particular case of trouble referred to by Mr. Jackson seemed to carry every evidence

that the source of it could have been in the metal and not in the type of moulding sand used. While admitting that permeability of moulding sand was an important factor, it was not the source of shrinkage trouble as described.

Hardness and Section Thickness.

Mr. A. Sutcliffe said that if a man in breaking up a cylinder broke off the foot, or a piece off at the jacket, or he took a piece out of the barrel, did he expect to get the same total-carbon and graphite content in all three parts? The barrel was much thicker. If he used low-carbon and also low-silicon iron, the foot and jacket were going to be white iron, *i.e.*, if he took the analysis of the barrel, as the barrel was the thickest part of the casting. These low-carbon and low-silicon irons were satisfactory for the barrel to a certain extent on account of withstanding wear, but the foot and jacket had to be machined; the metal in these two would be much harder, although it was all one casting.

Mr. West replied that it was to be expected that the thicker barrel section of a cylinder casting would differ in structure from the jacket walls, which in most cases were reduced in thickness to a minimum. The foot portion was usually about the same sectional thickness as the barrel walls, and because of this very little difference was noticed. What they aimed at was to get the structure of the walls correct, because of the important part it played in deciding the life of a cylinder block. The walls of the jacket could be produced under these circumstances without any signs of whiteness in the fracture, but to effect this, a very fine control upon the chemical analysis must be made.

Superheating Cast Iron.

Mr. Dawson agreed that the pouring temperature, and possibly more so the melting temperature, had a big influence on the segregation. It was quite possible also that there would be a difference in the resistance to wear between metal

taken up to 1,450 deg. C. and metal which went above that and was then reduced to 1,450 deg. C.

Mr. West said that the temperatures given in the graph were taken at the time of pouring, so that the initial temperatures must have been at least 50 deg. C. higher. The superheating of cast iron was occupying his attention at the moment; they would go on with it if it gave better results than were now obtained from the straight cupola iron, but he had an idea that with superheat they would not get the resistance to wear which was suggested. Dr. Piwowarsky had indicated that superheat was accompanied by dissociation of the pearlite and with a resulting separation of soft iron. It was necessary, therefore, to be very careful and very conservative as to what they were to expect. The cupola had been with them for many years and would be with them for many more years. However, if there were better and reliable methods of production than the cupola, the sooner they came into use the better for foundrymen, providing such were within the means of the foundry to purchase and make an economic proposition.

Mr. J. S. G. Primrose said that the problem of getting good cast iron to withstand the high duties now imposed upon it was reduced to a question of the proper microstructure. In every case the cast iron which behaved best was one in which they had an all-pearlite matrix, achieved chiefly by the correct composition and casting temperature, so that the graphite flakes were small and curly. Some day they would have to turn to an all-sorbite matrix as still better than pearlite, as other ironworkers have had to do, as in high elastic-limit ship plates and high-tensile wire. The resistance to abrasion could most easily be measured in the workshop or in the laboratory by means of the Amsler abrasion-testing machine, which could be seen in Birmingham to-day.

Mr. E. Longden said at one time they made bearings for large gas engines in a common Midland iron containing approximately 0.45

manganese, 1.3 phosphorus and 2.5 per cent. silicon, which, on remelting with scrap, gave about 0.4 per cent. manganese. These bearings were known to stand up well in service. During the war some bearings were made in a metal with low phosphorus and silicon and higher manganese, approximately 0.75 per cent., on the request of a Government inspector. Castings made in such special iron lasted only a few hours under similar service conditions, and were eventually replaced with the common low manganese, high phosphoric iron. Mr. Longden had repeatedly had a grey cast iron containing silicon 2.0 per cent., phosphorus 1.0 per cent., manganese 0.35 per cent. and sulphur 0.12 per cent., which was machined with great difficulty. This showed the bewildering and complex nature of cast iron.

Mr. West said he hoped to lecture in February before an engineering institute on "Resistance to Wear in Relation to the Structure of Cast Iron." Up to now the consideration had always been the resistance to wear in relation to the chemical composition, but he was now considering the question in relation to the structure. By casting successively thicker bars, he thought he could get the decomposition of the pearlite and have the same composition, and thereby altering the structure as the thickness of the bar increased.

London Branch.

THE APPLICATION OF PULVERISED FUEL TO THE FOUNDRY INDUSTRY.

By W. Boon.

The subject of the application of pulverised fuel to the foundry industry has been divided into seven sub-headings. Each of these sub-headings is perhaps of sufficient importance to warrant their being the subject of one complete Paper, so that to take anything like a complete survey of pulverised-fuel applications such as the one under review will necessitate a very curtailed description of each of the seven sub-divisions.

The purpose of this Paper is not so much that it should be in the nature of a very detailed technical discussion, but that a general survey of the whole field should be given to enable the uninitiated to form some comprehensive and clear idea as to the elements entering into consideration of installations of this character.

The equipment which may be installed to fulfil any pulverised-fuel application is, of course, a matter of first importance, and could only be correctly based upon experience which would dictate not only the type of machinery to employ, but the method of its arrangement and also the necessary auxiliaries which go to form the whole.

Types of Pulverisers Available.

The first section deals with the various types of pulveriser, their advantages and disadvantages and the particular use of each type. The selection of the right type of grinding machinery is often a matter of some difficulty in view of the scores of different makes on the market to-day. To discuss the relative and individual merits of such a large number of machines is rather out of the question, and it is proposed to divide

these machines into three main groups:—(1) The impact high-speed and attrition mills; (2) the ring-roll medium-speed grinders, and (3) the slow-speed ball and tube mills.

In the first category would fall such well-known machines as the Attritor, Resolutor, Simplex, Miracle, Bettington, Forplex, Kek, etc. In the ring-roll group would enter the Raymond, Rema, Fuller, Sturtevant, Bonnot, Bradley, etc., and in the last category would be included the Hardinge, Fuller Bonnot, Johnsons, Simon Carves, Krupp, etc. There are mills, of course, which also would come between these groups, for instance, a combination of the ball and impact mill would apply to two of the foregoing categories.

Group 1.—The high-speed mills coming under Group 1 have achieved a certain degree of popularity due to low initial cost as compared to the heavier type of grinders appearing in the remaining groups, and also the relatively low power consumption per ton of product. The reduction of material takes place in these mills by attrition and impact, and they usually consist of a central shaft which may be directly coupled to a motor, and to which is attached various sizes and shapes of grinding media, the whole enclosed in a metal-lined chamber, where the incoming material is shattered by a direct blow of the beaters and also by the impact of the material being hurled against the lining of the chamber, or again by direct shearing action.

Those depending more upon the shearing action effect, are constructed with one set of beater bars or pins stationary and the other revolving at a high speed. Other mills in this same group are constructed with rotating members operating in opposite directions.

Group 2.—Under the second group of mills the material is reduced and ruptured by compression, centrifugal force or spring pressure, or again a combination of these forces. In these mills the coal is definitely ground, that is to say, it passes between moving and stationary faces, which vary in construction in accordance with the various types.

Group 3.—In the third group the coal is reduced more by direct hammer blows, which is perhaps the best medium known for the reduction of material, being more effective than either attrition or grinding between the balls which form the charge. The ball mill is the slowest moving of any of the grinding machines, and is perhaps the oldest principle used for the reduction of material in use to-day. The ordinary hammer blow is the best method known to cause rupture and the ball mill makes more use of this principle than any other grinding machine. The mill is horizontal and the speed of the barrel is so arranged that the ball is lifted to a point near the top of the cylinder and its own weight will then permit it to drop on to the coal in the bottom of the barrel. A certain degree of grinding also takes place by the rumbling effect of the coal being mixed with the ball charge, but the greatest asset which gives the greatest production from this type of mill is undoubtedly due to the dropping or cascading of the balls from the top of the barrel.

In Group 1, the impact group, the coal produced is of a granular form and contains no large proportions of tailings, or, what the miller would term, "fine flour." Therefore, where the application is required for a furnace where the heat release is comparatively high, then the product from this class of mill would not be so satisfactory as that produced by the positive grinding mills. In addition to which, the high-speed mill must be guarded against the intrusion of foreign materials, such as tramp iron, and separating means have to be provided, usually externally to the mill, to prevent stray bolts or nuts getting into the machine with the coal, otherwise the beaters or hammers correspondingly suffer. Again, the grinding effect in the high-speed mills in this group is such that in the course of time, as wear takes place, the fineness of the product will suffer. Various external separators are provided in these mills, both internal and external, to offset this contingency, but, generally speaking, the falling-off

in the fineness of the product is so severe after, say, 400 to 500 hrs. of operation, that the output of the mill has to be seriously curtailed, or, alternatively, a coarse product will be provided, which causes trouble in the furnace and would result in the fuel being partially unconsumed.

With regard to Group 2, where the grinding is positive and the rupture is due to compression, the falling-off in the fineness of the product is not nearly so marked as in the impact machines, but as wear does take place and as loss of weight in the grinding media occurs, the output of any given mill will have to be reduced in order to provide the same fineness which the mill originally was intended to produce. The same remarks given above with regard to tramp iron apply to this category of mill, although the damage, due to the lower speed of the mill operation, would not be nearly so severe as in the case of the high-speed units.

The initial cost of the ring-roll mill is, of course, considerably in excess of the impact machine, but it produces a product which is more reliable and more uniform than the impact type of machine. The power required for driving this class of pulveriser would be generally higher than would be the case under Group I, but the author's opinion is that the value of the uniformity in the coal supply would more than offset the additional power requirements. The maintenance costs, comparing either Group 1 or Group 2, may not be of great difference. In Group 3—ball mills—the power characteristics are perhaps higher than in the other two groups, for the simple reason that the ball mill is not a well-balanced machine; also, the ball-mill type of pulveriser has the disadvantage of comparatively high initial cost, but against these factors could be set the better grinding ability of the machine, a more uniform supply of product, and entire reliability, due principally to the slow speed at which this type of pulveriser operates. Its maintenance cost is undoubtedly the lowest of any type of grinding machine yet produced, neither does this mill require any auxiliary

mechanism for the prevention of tramp iron or extraneous matter getting into the mill with the coal—in fact, any materials of this character which would pass the coal feeder would remain in the mill and continue to do some service in the way of reducing the material to be ground. The replacement costs of these mills simply depend upon the addition occasionally of more balls, which can be fed into the mill with the coal without stopping its operation or interrupting the service.

Power Consumption.

There has been much controversy and more writing about the power consumption of various pulverisers than one can well assimilate. Such comparisons are usually quite futile and can only appeal to the uninitiated. The comparison of power consumption, which, of course, is the highest item in the cost of producing pulverised fuel, between the different mills which are on the market to-day, can only be made under exactly similar conditions, that is to say, with the same product and for the same fineness. It is only commonsense to say that to pulverise any given material to a definite fineness must require the same amount of work to be expended in any machine. Differences in power, therefore, can only lie in the mechanical efficiency of the machine itself. It can be easily seen and freely admitted that the better balanced high-speed impact machine must have a better power characteristic than, say, the ball mill, which is a slow-speed moving cylinder and badly balanced. To illustrate this point further, the ball mill, with its charge, requires almost the same power to operate it when the mill is empty as when it is normally producing. The ring roll is also a better balanced machine than the cylinder of a ball mill, hence one may concede that it will have a better power consumption.

The advantages and disadvantages, therefore, of the particular types can be summarised in the fact that Group 1 may have a better power characteristic than Groups 2 and 3. Groups

2 and 3, however, produce a more uniform and finer product than Group 1. Maintenance charges in Groups 1 and 2 are considerably in excess of Group 3. Groups 2 and 3 are more reliable mills for long service than Group 1.

Fundamental Considerations.

The particular use to which each type should be put is a difficult question to answer, and rather than state the exact types of furnaces or boilers to which each group may be applied, it will suffice to say that this question is better decided by the heat release which a given application is required to undertake. That is to say, what is the B.Th.U. quantity to be consumed per cub. ft. of combustion volume per hour? This rate is a vital factor, and is unfortunately too frequently misunderstood or ignored when considering pulverised-fuel applications. Where the heat release is low, that is to say, a figure up to 30,000 B.Th.U. per cub. ft., then it is perfectly feasible to use the high-speed mills, providing that no other considerations would rule out this machine.

Where the heat liberation is beyond this figure, then better grinding is needed than can be provided in the impact machines. A golden rule to follow is the greater the heat release, the finer and more uniform the grinding. By uniformity is meant not so much that the product should be exactly the same as regards size, but that there shall be no large proportion of over-size material produced. How much fine material is produced is immaterial, excepting that the fineness of the tailings or flour gives always better burning conditions, but it would be uneconomical and unnecessary to produce a wholly fine product. This point will be pursued somewhat further later, where a discussion as to types and characteristics of coal, fineness of grinding and effects of moisture is given.

Types and Characteristics of Coal.

It would perhaps be surprising to say that the characteristics of English coal vary enormously. They vary not only in their structure

and their hardness and resistance to rupture, but in their physical properties. The type of coal which may be used in any given installation has a distinct bearing also on the type of mill which is to be employed. Take, for instance, bituminous coals. If one employs impact machines on Durham coal, which is exceedingly hard and tough to grind, the product would be so bad and the maintenance so high that new internals would have to be put into some of these types of mills perhaps after 300 working hours, or even less. At the other extreme, one could take a Kent coal, which is of a very friable character, and the same machine would easily last 1,000 hrs. without renewal of any beaters, yet the analyses of the two coals may be closely approximating. It is obvious, therefore, that where the harder coals exist, the impact type of pulveriser would be a very costly installation, notwithstanding its better power characteristics and its cheaper initial cost.

The fineness of grinding, and the decision as to what degree is necessary for any given application, is definitely ruled by the time necessary to burn completely any given particle, and therefore by the rate of combustion and the path and velocity of the particle. The actual rate of combustion of any fuel is determined by:— (1) The temperature of the combustion chamber; (2) the concentration of the mixture of air and fuel, with which may be included the intimacy of mixing and the effect of dilution by inerts, such as nitrogen and carbon dioxide; (3) turbulence, in so far as it results in the movement of the fuel particles relative to the oxygen molecules; and (4) chemical and physical properties of the fuel itself.

The higher the temperature, the higher is the speed of any chemical reaction, but as coal is a bad conductor of heat, a large lump of coal will take much longer to reach the temperature necessary for reaction than the same weight of small particles suspended in the heating medium. Further, considering only the surface effect, the

small particles will have a greater ratio of air to weight than the large, and will therefore attain a high surface temperature much more readily. Quick ignition will not only be assisted by this, but also by the more rapid evolution of the volatile constituents of the coal. In the same way powdered fuel will also pass through the remaining phases of combustion more quickly than lump coal.

With regard to turbulence, solid fuel remains stationary on the grate, whereas finely-divided fuel would be capable of being whirled about the combustion chamber with any required degree of violence. The whole argument, therefore, of fineness resolves itself into the question of the time element. The shorter the time that is available for the consumption of a particle of coal, then the smaller must be its size. Therefore, where the degree of heat-release is comparatively high and the flame path is a short one, it becomes essential to have not only good fine grinding, but a uniform product. By this is meant the absence of any oversize. To burn a cube of coal measuring 3 centimetres along its edge, then the combustion of this cube, after being pulverised by grinding, will proceed 1,500 times quicker than the cube itself. A particle of coal through 170 mesh will have a size 0.02 c.c., so that the cube will contain, or by grinding be resolved into, 3,400 million dust particles. The original cube had a superficial area for the reception and emission of heat of only 54 sq. cm., whereas the total superficial area of the dust produced from it is 8,200 sq. cm., or 1,500 times as great.

An excellent specification for good grinding with the types of mills in Groups 2 and 3 would be no residue on 60 mesh, and it is certain that if this were maintained the resulting product would be suitable for nearly every metallurgical application, and it also would be an ideal fuel for boilers. It is the oversize which is the enemy of all pulverised-fuel burning, and if this can be taken care of, the fines will look after themselves.

Effect of Moisture.

The effect of moisture on coal has a very important bearing throughout the pulverised-fuel plant, and as most of English coals are highly hygroscopic, the moisture content is a point to which too much attention cannot be given. In the past, coal has been sold so easily per ton, or by the truck, under no definite specification, that the suppliers had a very pleasant time of it, putting as much water into the coal as it would possibly hold and selling that to the consumer as heat value. The coal factor is having an increasingly difficult time, as the coal consumer is more and more specifying his definite requirements with regard to the fuel, and is keeping a much closer scrutiny on the coal which is being delivered than he ever did in the past. This condition of affairs is exactly as it ought to be. Coal has been so cheap in the past that users have not minded very much if it did contain a great deal of foreign matter. The economies, however, which have to be practised in most industries to-day, coupled with the high price to which coal has climbed, necessitate a very much closer scrutiny of the coal purchased than ever was the case before.

The coal purchased for pulverising is frequently an unwashed product, and, as such, should be reasonably dry, that is, below 5 per cent. of moisture, particularly so when it is procured from a colliery whereby the transport time between the producer and the consumer is not very great. Washed coal would contain normally about 8 per cent. of moisture as delivered. This moisture content detracts from easy grinding; the higher the moisture in the fuel the more difficult becomes the grindability of the coal, because of the easily-understandable fact that the particles, after powdering, congeal together; in other words, ball up, so that the result of delivering such congealed particles into the furnace would considerably nullify its efficiency. Apart from the inefficiency of the furnace, the output of the grinding mill is considerably reduced, hence definite steps must be taken to deal with this factor, as and when it

arises. Where pulverisers are directly connected to furnaces, the admission of hot air into the mill is sufficient to overcome the disabilities of the coal with regard to grinding, but under such circumstances the moisture-laden air is delivered into the furnace and has to be driven off at that point. It is therefore uneconomical to use a coal with a heavy moisture content if at all possible to avoid it, and in the case where coal is stored after pulverising, in a bin or hopper, it is imperative that this fuel should be as free as possible from moisture, and that the moisture-laden air in circuit in this bin should be effectively vented to atmosphere. Alternatively, the coal may be dried prior to pulverisation. The installation of drying equipment is, however, an expensive item, and should be obviated, if possible, by the purchase of a reasonably dry coal in the first instance. The collieries can supply dry coal, and will do so if the demand is sufficiently insistent.

English coal is surprisingly hygroscopic after pulverisation, much more so than the American coals. Ordinary Midland slack, after pulverisation, dry, will absorb, during 24 hrs., nearly 4 per cent. of moisture, whereas American coal of almost the same analysis will only take up in the same time 2 per cent., under natural air exposure.

Centralisation *versus* the Unit System.

Much has been written with regard to the claims for the so-called central or bin system, as opposed to the unit application. At the risk of going over old ground, it would perhaps be well clearly to indicate what the two types embrace. The unit system is understood to mean a pulveriser applied directly to a furnace or boiler, and without any intermediate storage of powdered coal between the pulveriser and the furnace it is serving.

The central system means a collection of pulverising machinery on one site, and the delivery of the pulverised product into storage bins or hoppers. From these storage bins the prepared coal is delivered to the various furnaces by

means of feeders on the bin and methods for carrying the coal to the furnaces.

The consideration as to which type of equipment is to be used depends almost entirely on site conditions and methods of operation. Where one or two furnaces are to be applied, it would seem unnecessary to contemplate any other system than applying a single pulveriser to one or two furnaces. On the other hand, where a series of furnaces or boilers are in contemplation, then it may reasonably be assumed that a central system would be cheaper in capital cost, as one pulveriser could be used to provide the necessary coal into the bin, which may serve a multiplicity of furnaces. A pulveriser working in this way produces at its full output and has a better load factor than say a machine directly coupled to a furnace and which may have fluctuating coal requirements. In other words, a pulveriser applied to a single furnace would not have nearly such a good load factor as the one which is working steadily and at full capacity for the supply of a stock bin.

Another factor to be taken into consideration would be the distribution of the raw coal; presupposing that a number of furnaces were in operation and each furnace was supplied with its separate pulveriser, then the raw coal would have to be carried to those various points and each mill would have to be fed independently. In a central system, all the raw coal would be brought to one spot and fed into perhaps one mill. In other words, the unit system would necessitate carrying coal round the works premises, and the central system would obviate this entirely. In addition to which, the works would be very much the cleaner and would provide more useful working space if it were free from coal hoppers or machinery adjacent to the furnaces.

The comparison of capital cost between these two systems is a matter of simple arithmetic. In the case of two or three furnaces, it would probably be cheaper to install a unit machine to each. Beyond that number, the central system would probably be the cheaper installation.

Apart, also, from these considerations, the fact that a stock bin containing prepared fuel is available, permits of continuous operation from this source without any definite reliance being placed on the continuity of operation of the pulveriser—that is to say, that a pulveriser on the central system can be started and stopped at any time without any interruption to the supply, providing only that storage is available in the bin when such a stoppage occurs.

On the other hand, any interruption in the running of the unit machine entails a stoppage of the furnace, and in the case of melting furnaces such a contingency would have grave results. Where conditions are such that furnaces are required to run continuously for 24 hrs. a day, it would be unwise to trust such a service as the unit application, and if, as is possible, standby machinery were installed, then again the capital cost is beginning to assume such proportions that the central system would be the cheaper proposition. The mills in Groups 2 and 3 are definitely indicated for central systems, and the mills under Group 1 would not be feasible under this scheme, but for the unit system all three groups could be utilised.

Transporting Coal within the Works.

The question of transporting pulverised coal throughout a works premises, pre-supposing that a number of furnaces were to be fired and in widely scattered positions, would entail means depending upon operating conditions of each particular shop. For instance, one department of a works may conceivably be operating on day and night conditions, whereas other sections of the same works may only operate one single shift. Upon such considerations would depend the choice and class of equipment to be employed. It may be that if a central pulverising plant were installed for a series of widely scattered furnaces, the best policy would be to adopt sub-stations, or storage bins in separate departments and to serve these storage bins from the main station by either air transport of the fuel,

or mechanical conveyance. The particular furnaces which each sub-station would deal with could be fed by a distributing pipe line or circulating system which would convey the fuel as a mechanical gas to the different furnaces from each main, tappings would be taken as and when required.

An instance of this would be an annealing shop with, say, a battery of ovens. The coal supply main would pass closely adjacent to these ovens, and tappings would be taken to each one individually by means of cut-off valve and pipe connections to the burner. Air would be the carrying medium, by pressure sufficient to convey the coal throughout the pipe main and to return back again to the storage bin whatever quantity had not been consumed at the furnaces. This means of serving a multiplicity of furnaces has been widely adopted, both in this country and on the Continent, and for this purpose no better or more reliable method has yet been devised. It is perfectly true, however, that the conveyance of coal by means of air through a long distance is an expensive item in power, and if a reasonably cheap mechanical means could be devised for this duty, then a distinct advance would be made. Continuous experiments are being carried out in this connection, and there is no doubt that ultimately a mechanical method will be produced which will uniformly serve a variety of furnaces and will offer a means of controlling the exact quantity of coal required at each individual burner.

The storing of pulverised coal in bins is a matter which is to-day comparatively simple. With the highly volatile coals it is essential, however, that reasonable precautions should be made to prevent spontaneous combustion. Bins should be provided so that all external air is excluded, and the moisture content of the coal being put into the bin should not exceed 5 per cent. as a maximum, otherwise the feed out of the bin becomes sticky and irregular. A low moisture content is particularly important when the coal has to be conveyed long distances through pipe lines.

The data available of operating figures are rather sparse for the foundry industry, and whilst the author has a mass of figures available for forge furnaces, re-heating furnaces, etc., the foundry applications are more or less confined to malleable melting furnaces, chilled-roll melting furnaces, malleable annealing and core ovens, and curtailed results on rotary melting. With a malleable-iron air furnace, of which a considerable number are now working under pulverised-fuel conditions, and which seems to be an ideal application for pulverised fuel, the fuel to metal ratio varies from 2.5 to 1 to 3 to 1, using a raw fuel of the following approximate analysis:—Moisture, 8.2; volatile, 33.0; fixed carbon, 60.0; sulphur, 0.84; and ash, 7.0 per cent. The calorific value was 13,300 B.Th.U. and the fuel cost about 17s. per ton in the Midlands, whereas a similar furnace under hand-firing conditions would use best top hards costing in the region of 24s. per ton, and giving a fuel ratio under best conditions up to 2.25, with a melting speed of about 30 min. per ton, whereas under pulverised-fuel firing the melting speed is improved to 20 min. per ton.

Annealing Ovens.

With regard to annealing ovens, again on black-heart malleable, over a long period of time records have been taken on a battery of fifteen ovens, all pulverised-coal-fired. Each oven is of 25 tons capacity, and the average coal consumption gives a figure of 6 cwts. per ton of finished castings, and again using the same cheap coal as in the melting furnace. Under hand-firing, for the same furnaces and work, the coal consumption was 10 cwts. per ton of best top hards. In addition to which, the life of the annealing pans is increased to an average of 12 heats. In white-heart malleable annealing the consumption of coal would, of course, be relatively higher because the process is carried out at a higher temperature than is the case with black-heart, and also the castings are more firmly packed in the boxes to prevent distortion than is the case

with black-heart, the temperature for the black-heart being 850 deg. C. and for the white-heart 980 deg. C. The fuel consumption under pulverised-coal firing per ton of finished castings for white-heart may reach 22 cwts., and the life of the annealing pans would not be in excess of 8 heats.

Some success has been achieved in the application of pulverised fuel to core ovens, but unfortunately no actual test figures are available. The net results, however, have been such that on a 25 per cent. fuel reduction, an increase in core output up to 50 per cent. from the same ovens has been achieved. The application is a comparatively simple one, the original flues being utilised with a simple type of burner projecting directly into the flue. Access, of course, must be available to flues of this character, because of the removal of the fine ash which accumulates. There is, however, usually ample opportunity and time for the removal of any accumulations.

Chilled-Roll Furnaces.

A considerable advance has also been made in the application of pulverised-fuel firing to chilled-roll melting furnaces. This trade, as is well known, is most conservative, and any innovations which may depart from standard practice have to be treated with some delicacy.

To an outsider, such as the author, the fabrication of chilled rolls always seems to be attended with a great deal of ceremony and ritual, and a certain amount of haphazard method which does not seem commensurate or in keeping with modern practice. Whether such a condition of affairs is justified, or whether there is more in the ritual than meets the eye, the author is not sufficient of a metallurgist to judge.

During six months of observation and tests on a 12-ton double reverberatory old-type melting furnace, which was converted from hand-firing to pulverised-fuel firing, the following interesting results were obtained:—

Normally, under the old conditions, this furnace consumed 1 ton of best top hards coal

costing 24s. 6d. per ton of metal cast, and in the first week of operation under pulverised-fuel conditions, the best results gave 12 cwts. of Hollywood small slack costing 15s. 6d. per ton. The time both for bringing the furnace up to heat and for the melting period was reduced, and after a considerable number of tests were run, the following definite conclusions were reached:—

*Heating time—that is, for bringing the furnace up from cold to charging—*80 *min.*

With the fuel feed at about 33 *lbs. of coal per min., the furnace was then reduced to a low coal feed during the time of charging, and the average charging time was* 45 *min.*

The charge consisted of scrap, pig and large pieces of broken rolls.

The melting time was fixed at the rate of 23 *min. per ton of metal charged and the fuel feed was fixed at* 43 *lbs. of coal per min.*

After the first test-piece had been taken, the coal feed was reduced to 25 lbs. per min. until tapping, which period usually averages 50 min.

The fuel ratio in the various tests had varied more on account of the altering time, that is, after the first test-piece had been cast, than for any other consideration.

The fuel rate for bringing the furnace up to heat was constant, the melting period was also fairly constant, but the altering period was a variable, which caused considerable discrepancies from 12 to as high as 17 cwts. per ton of metal cast. As experience was gained in the stability of the combustion conditions, the altering period for the adjustment of the metal bath was slowly reduced, in other words, the operators began to rely upon the uniformity with which the elements were burnt out or changed due to combustion conditions, and a ratio from this furnace is now being obtained of 10 cwts. of this cheaper coal per ton of roll cast. In no instance, right from the commencement of the first melt, was a bad roll run, and it will be appreciated that time is the only factor which definitely

proves the quality of a roll, six months has elapsed and there has been no single complaint about the quality of any roll.

Rotary Melting Furnaces.

The most recent development of pulverised-fuel applications and one which is probably of more interest to the foundry than any other, is the rotary melting furnace. Of this type, probably the Brackelsberg and Sesci are the best known, and have undoubtedly been the most successful, particularly the latter. There is to be presented some definite and detailed data on this subject at the meeting of January 21, but it would perhaps not be out of place to give some preliminary figures which have been achieved with the Sesci furnace.

A 5-ton charge for high-grade grey-iron castings was poured and completed in $2\frac{3}{4}$ hrs. working, starting from cold, and a second charge was poured in 1 hr. 50 min. The metal has a high degree of superheat and is normally much hotter than cupola-melted material. The furnace is making, in addition to high-grade iron castings, special pig-iron for sale to other foundries. This is somewhat in the nature of a distinct development, when the British foundry industry will have an opportunity of testing out special high-grade pig-iron cast in chills of British manufacture.

The following data are from the Terni Steelworks, in Italy, which are owned by Messrs. Vickers, and where armaments of all sorts are manufactured. Recently a Sesci 2-ton furnace was installed for experimental purposes. Their aim was to make locally, with steel scrap, synthetic iron which would replace hematite. To have effect steel had to be recarbonised above 3 per cent. The first charges were made up partly of steel and partly of hematite, but on the third day of working hematite was completely cut out and the charge was made up of 100 per cent. steel scrap. Recarbonising material was either petroleum coke (which gave the best results) or anthracite. The plant was run for a whole month, night and day, making synthetic

iron only and casting it into pigs. The iron produced was to the following analysis:—Total carbon 3.2, silicon 1.3, manganese 0.6, sulphur 0.05 and phosphorus 0.05 per cent. This pig was transferred to the open-hearth furnaces and behaved in exactly the same way as hematite. A test pouring from this iron, casting vertically in green sand, gave a tensile of 25 tons per sq. in.

The results of 5 weeks' operation were, apparently, so convincing and conclusive that the Terni Company placed a further order for three 10-ton Sesci furnaces. The importance of this development will at once be realised. Wherever steel scrap is available at a low price the rotary furnace offers the possibility of making locally synthetic irons of any reasonable analysis, depending only on the method employed for recarbonising. Recarbonising is now carried out so effectively at Terni that they can rely on an efficiency of 72 per cent. with petroleum coke, with a variation of only 1 per cent. With anthracite, the efficiency is between 63 and 65 per cent. This means that recarbonising can take place almost exactly at the point required, and, indeed, with far greater accuracy than a blast furnace can possibly do.

The melting cost at these works comes out at 10s. per ton all told, and the anthracite which is used is imported. The Sesci rotary furnace is, therefore, no longer to be considered as a furnace for producing high-grade iron or malleable-iron castings, but has definitely become an adjunct of large steelworks for melting scrap and transforming steel scrap into an iron ready for steel-making. The rotary furnace has also come to stay in the malleable-iron industry, and very impressive figures have been obtained from three separate Continental works, where operation has been of a sufficiently long period to warrant the results being quoted.

The fuel consumption has averaged 16.3 per cent. average over all the charges for a casting temperature above 1,600 deg. C., and allowing for tapping spread over 30 to 45 min., the actual fuel consumption for melting only is well below 14 per cent. Only 10 per cent. of the charge is

hematite, and the remainder being foundry scrap and steel scrap. The heat is completed under 15 min. a ton from cold and 12 min. a ton on the second heat. The fuel used in the Sesci furnace is washed anthracite slacks, and the cost of material of this description of excellent analysis is about 16s. to 22s., depending upon the situation of the works from the source of supply. As one who has followed the development of the rotary furnace, it is the author's opinion that the Sesci furnace is an outstanding achievement in the process of metallurgical applications, and the foundry industry is to be congratulated on the developments and general improvements which have taken place in their methods and materials, perhaps more so than any other industry, in the metallurgical field.

Some interesting data on a rotary furnace operating at an important works on the Continent have been obtained. Most founders are anxious to have some reliable data concerning the cost of rotary furnace linings. The figures to be quoted have an added interest, because they have been verified by a Branch member, Mr. John Shaw, who is well known as an active and astute investigator.

This particular furnace has run for a considerable period of time and has consecutively done 130 heats before any lining renewal has taken place. Seventeen heats per week are taken from the furnace, and the total metal produced before any repairs have been undertaken has been 650 tons. The total quantity of refractory in the new furnace is 27 tons at a cost of £4 per ton; only $\frac{9}{14}$ of the total lining is, however, renewed each time. The cost, therefore, for material only on this base is 2.15s. per ton of metal cast, to which must be added labour. For this two men are required for two days breaking down and preparing the furnace, and four men are required for three days ramming up and finishing. A total equivalent to 16 day shifts at 10s. per shift, which gives an added cost for labour of 0.25s. per ton of metal cast, making a total, both for labour and

material, of 2.40s., or, say, an outside figure of 2s. 6d.

Effect on Refractories.

The effect on furnace refractories of pulverised-fuel applications is generally that refractories have a longer life than under any other condition of firing, providing that reasonable precautions are taken in the introduction of the fuel into the furnace. Originally faults in pulverised-fuel applications were prolific in the fact that in the fuel and air stream entering the furnace the particles were allowed to scour or sweep the walls of the chamber. This condition naturally sets up erosion of the brickwork, which, however, was purely a mechanical condition and could easily have been overcome. To-day design, both of burners and air control, can permit of the flame's direction being regulated during the time the furnace is in operation, both as to length of flame and direction. A direct impingement of a stream of fuel on to refractories should at all times be avoided, as, naturally, brickwork will not last long under such severe conditions, but with well-designed furnaces and correct flame travel, the life of the brickwork in any type of furnace can be guaranteed to be much longer than would be the case under hand-fired conditions. The reason is fairly obvious; for one thing, the furnace is under more stable heat conditions; there is not the same fluctuation of temperature due to periods of cleaning fires or by excess quantities of air whereby stresses are set up in the brickwork. One of the chief factors that determine the life of the refractories is the velocity of the flame passing through the furnace; the secondary air, therefore, should not be admitted to even melting furnaces at a pressure exceeding 4 in., unless, of course, the burner is of such a type that a certain amount of additional pressure is necessary to overcome the resistance in it. Literally, hundreds of patents have been taken out on different types of burners for pulverised-fuel firing, 90 per cent. of which have been more or less futile. Experience is the

teacher which dictates more than anything else the best type of burner to use for any given application, and one little incident which rather illustrates this is perhaps worth relating. A certain melting furnace fired by pulverised coal had been operating with flat fish-tail type burners, and a rotary type of burner was substituted at the insistence of a high-pressure salesman. The promises made were that the fuel saving would repay this installation in probably three months and that the furnace would in every respect operate better. The trial, however, was a very bitter disappointment, both to the salesman and also to his client. The burner lasted two weeks, during which time not one single melt was taken out of the furnace to the usual scheduled time. At the end of the two weeks the furnace crown had dropped in and the base of the stack had been severely damaged. The furnacemen were patient individuals, and lasted out the fortnight, certainly not without passing some very pertinent remarks about its operation, and during this fortnight of working the coal-consumption ratio was exceeded by 15 per cent., so that what was left of the burner was removed and the old fish tails were put back again. To propose a rotary burner for the condition requiring a long flame was, in the first place, quite wrong, as the flame spread, and the scouring action of the particles which were thrown out against the sides and roof of the furnace was quite against a long life of the refractories.

Effect of Ash.

Ash and slag formed in pulverised-fuel furnaces is deposited in a variety of ways, and, of course, is greatly dependent upon the original characteristics of the ash content in the coal and of the furnace design. Generally, the deposit falls into the following categories:—(1) Viscous liquid slag on the hottest part of the furnace walls, usually formed at a temperature of about 1,200 deg. C.; (2) as a partially sintered accumulation on the walls of the

furnace, the friability of which depends on the temperature of the deposit, which ranges from 1,000 to 1,300 deg. C.; (3) as a deposit of the large ash particles from the floor of the combustion chamber which have solidified before touching any brickwork. For the ash to be deposited in a powdered condition the maximum temperature of the furnace walls seems to be about 900 to 1,000 deg. C.; and (4) smaller ash particles carried along by the draft and deposited in various parts of the flue system according to the relation between the gas velocity and the size of particle.

The average diameter of the particles taken from the floor of a combustion chamber in a particular test case was in the region of 100 microns. The surface of the larger particles are found, on examination under the microscope, to be covered with small particles having diameters between 1 and 6 microns, which would appear to indicate that these larger particles are built up from a multitude of small ones. The average diameter of the coal particles burnt in the furnace is about 10 microns, and assuming 15 per cent. of ash the calculated diameter of the resulting ash particle is 4.2 microns. The number of these small particles required to build up one particle of 100 microns is between 30,000 and 50,000, and this figure gives some idea of the turbulence which must exist in the combustion chamber of a furnace. The diameter of the largest coal particle is about 180 microns, so that it is unlikely that any ash particle having a diameter greater than 75 microns will be formed from a single coal particle.

Measurements on a sample taken from a dust collector gave a mean statistical diameter of about 8.2 microns, the largest solid particles having a diameter of 120 microns. In addition to the solid particles there are a number which are hollow and are in fact bubbles of silica. It is suggested that these bubbles are formed by the expansion of the gases from the particles of coke enclosed in molten ash. The slag removed, of course, from the molten iron is dark

grey in colour and very heavy, due to the large quantity of iron oxide which has united with the silica. The temperature of deposition is between 1,400 and 1,700 deg. C., depending again upon the composition of the ash. Where the temperature of the refractory walls of the furnace or the combustion chamber is slightly below the fusion point of the ash, the liquid particles of slag impinge and collect on the walls, roof and floor of the furnaces. This slag eats into the brickwork and forms a coating which it is impossible to remove without damage to the refractories. The temperature of deposition varies around 1,200 deg. C. and upwards.

The liquid particles of ash have almost solidified before they impinge on the walls, but are just hot enough to sinter together before they touch. The deposit has the appearance of plant-like growths, and is very friable and may be crushed between the fingers. The temperature of its deposition is between 1,000 and 1,300 deg. C. The effect of ash generally is undoubtedly detrimental, whether the furnace operation may be in the form of pulverised-fuel firing or otherwise, and consequently all fuel applications are tremendously improved with the reduction in ash content of the original coal. It is a matter of economics, however, what coal shall be used on any particular installation, and it is being realised perhaps more to-day than ever before, that it is frequently cheaper to buy a dearer coal. Particularly so is this applicable in pulverised-fuel plant, where grinding costs have to be faced, because not only is power expended on the grinding of useless ash, but ash forms the hardest part of the coal which has to be ground, and consequently wear on the grinding media is more consequent upon ash content than upon any other state of the coal.

If, therefore, the ash content is reduced, the grinding cost per ton of coal is commensurately better. The production costs of pulverised coal depend chiefly upon the power consumption and price paid for such power. Taking an example of a ball mill from actual practice, working on

Midland bituminous coal, the figures for a 10-ton capacity machine are:—

Depreciation and interest	1.68d.
Maintenance	0.85d.
Labour	0.70d.
Power, 12 kw. at 0.5d. per kw.	6.00d.
	9.23d. for pulverising per ton of coal produced.

In conclusion, there are now over 400 metallurgical installations operating successfully with pulverised coal in this country and Europe alone, many of which plants are of large size and which have been extended from initial small beginnings. Thus continued progress has been made in this field, in spite of the general industrial depression.

DISCUSSION.

Mr. H. C. Dews complimented the author upon his valuable Paper, containing, as it did, so many definite statements, backed up by concrete figures. He also expressed appreciation of the tribute Mr. Boon had paid to the foundry industry in connection with the development of the Sesci furnace. It was not often, he added, that the industry was congratulated upon enterprise in new developments, and a tribute from one so obviously knowledgable as Mr. Boon was very deeply appreciated.

An Engineering Centenary.

Mr. J. W. Gardom pointed out that a hundred years ago this month the first patent for pulverised-coal firing was brought out, and said the fact that its development to the present stage—which Mr. Boon had admitted was not yet perfect—had occupied so long a period indicated lack of push on the part of British manufacturers. It had been introduced by an Englishman—Mr. Dawes, of West Bromwich, he believed—but had been developed in America. The Americans had a type of coal

different from that obtained in this country, and they had favoured the central system of coal grinding and distribution, which had many defects. In the first place, it was a very costly system, and was applicable only to big works, so that when pulverised-fuel firing came back to this country it was rather slighted. Another disadvantage from which the development of pulverised-coal firing had suffered was the fact that it was adopted mostly for steam-raising pur-

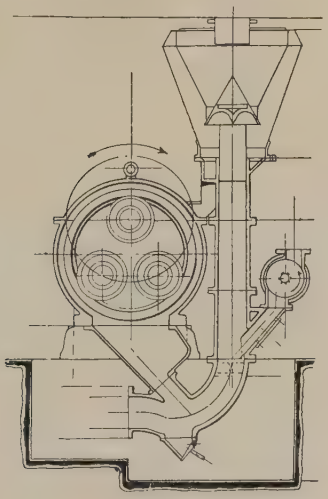


Fig A.—A Typical Ring-Roll Mill.

poses, for which it was supposed to be extremely efficient; the owners of such plant worked a great deal on the peak loads, and the result was that if difficulties occurred with the pulverisers and there was a reduction of efficiency they immediately scrapped the pulverised-fuel system of firing. He had learned only that day that the owners of one of the big power stations in London had taken out pulverised-coal firing and had substituted stoker firing. That was rather a disappointment to him personally, because he was a great believer in pulverised coal.

Points about Pulverisers.

Discussing pulverisers, he emphasised that an essential was accessibility to all parts for the purpose of replacement when they were worn. Wear was bound to occur, and one was inclined towards the use of slow-speed pulverisers because the wear in such pulverisers was definitely less than in those in which higher speeds were attained. He believed there had been introduced a pulveriser in which the fines were separated

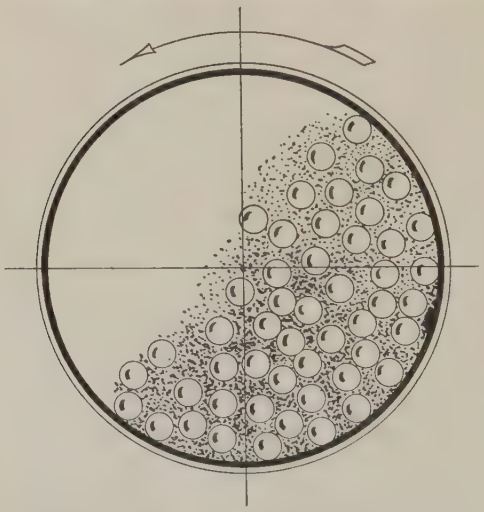


Fig. B.—Showing the Cascading Action in a Ball Mill.

from the coal by air before it went into the pulveriser for crushing, thus saving time and energy which would otherwise be occupied in passing this separated portion through the crushing plant. The coal was also removed immediately it was ground. Commenting upon Mr. Boon's point that the suitability of a coal for burning in the pulverised form depended a great deal upon its ash content, he said that not only the suitability of the coal for burning, but also the life of the refractory, depended upon the ash content of the

coal. Having regard to the uniformity of the heat in a pulverised-fuel-fired furnace the refractory used must have a longer life in such a furnace than in one fired by other means, provided, of course, that one took care of the extra heat generated by pulverised fuel. When certain coals were burned, however, there was formed a slag which adhered to the refractory, ate into it and damaged it very quickly. With regard to fineness of grinding, he was glad that Mr. Boon had not urged that all pulverised coal must be sufficiently fine to pass 200 mesh, or that 95 or 99 per cent. must pass 200 mesh. He welcomed Mr. Boon's statement that fuel which would leave no residue on 60 mesh would be suitable for nearly every metallurgical application and would be ideal for boilers, for he believed that, in the past, fineness had been very much overdone. It must be borne in mind that greater fineness meant the expenditure of more power for grinding, and greater cost. The cost of grinding anthracite was definitely greater than that of grinding bituminous coals, because the anthracite had to be ground finer in order to burn. Therefore, he had been rather surprised that Mr. Boon had not mentioned in greater detail other furnaces, such as the Brackelsberg. The Sesci furnace burned anthracite which had to be ground to an extreme fineness and burned with high-temperature secondary air, and he did not think it had any advantage over the bituminous coal-fired furnaces.

Unit *versus* Centralised Systems.

It seemed to him that Mr. Boon had contradicted himself when discussing the unit system *versus* the central system of distribution. When illustrating the central system, Mr. Boon had shown the use of a ring main for carrying the pulverised coal from the pulveriser to serve a number of burners and back again to the pulveriser; later on, however, when discussing the malleable furnace, he had stated that it was impossible to divide the coal and air streams equally when supplying two burners from one pipe. If it could not be done in one case, it

could not be done in the other, and the arguments in favour of the central system went by the board if it were impossible to vary the air conditions satisfactorily. He gathered that when discussing the central system Mr. Boon had had in mind big installations such as those existing in America. Discussing the unit system, Mr. Gardom said that its only disadvantage was the possibility of breakdown. Breakdowns were bound to occur, however, in any mechanical apparatus. It was true that in a pulverised-coal-fired furnace the heating was more uniform than in any other, but if a unit broke down so that the supply of coal to the furnace was stopped, the temperature would fall. He suggested, however, that the difficulty might be overcome by some storage system as a go-between, to operate in the event of a breakdown. A small amount of pulverised coal could be stored so that if any grinding unit broke down there would be sufficient pulverised coal available in storage to keep the furnace going for an hour or two while the grinding unit for that furnace was being repaired.

The Case of the Power Station.

Mr. Boon, replying, said that in modern power stations pulverised-fuel firing could show little better efficiency than mechanical stoking, when the costs of pulverising fuel were taken into consideration, unless the price of the coal used in the pulverised-coal-fired system was less than that of the coal used in the mechanically-stoked plant. If he were a power-station superintendent, and had a choice, he would use mechanical stokers for a plant up to a definite boiler size, unless he could use a cheaper coal for pulverised-fuel firing than for stoker firing; the efficiency difference between the two plants was so small that it did not pay the grinding costs, so that the extent of any saving to be effected by using pulverised-coal firing was dependent on the difference between the cost of that coal and the cost of coal used in the mechanically-stoked plant. The power stations in London had not the same advantage as had the power stations in

the Midlands, for example, in the matter of obtaining cheap coals. At one time the capital cost of pulverised-fuel firing plant was much higher than that of stoker plant, but at present they are practically equal. The mechanical stoker had a definite limitation in regard to the size of boiler it could deal with, however; it could not, for instance, effectively deal with a boiler giving 30,000 lbs. of steam per hour. During the last ten years the efficiency of

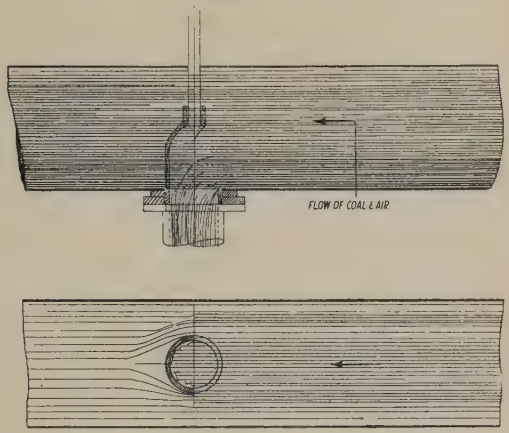


FIG. C.—SHOWING HOW THE SUPPLIES ARE DRAWN FROM A CENTRALISED DISTRIBUTION SYSTEM.

mechanical stokers had increased enormously, and he attributed that to a considerable extent to the competition of pulverised-fuel firing.

Discussing the grinder referred to by Mr. Gardom, which provided for the separation of the fines from the coal before it went into the plant, Mr. Boon said he believed Mr. Gardom had in mind a particular ring-roll mill. He illustrated its operation by means of a sketch, and showed how any part of the coal which was fine enough for use without grinding did not enter the mill but was carried past it by the air

stream (Fig. A). Hot air could be used at the air inlet. The coal ground in the mill might be returned through the mill many times—perhaps 50 or even 1,000 times—and the mill was very accessible. As a ring-roll mill it was certainly an excellent one, but it was expensive. It had to be stopped for renewals, and he favoured the ball mill because that had not to be stopped; in cement works, ball mills were being run continuously from one week's end to another. Such advantage as there was in separating the fines from the coal before grinding was dependent, of course, on the proportion of fines in the coal, but in normal coal the proportion was not very great.

All ball mills now used in modern pulverised-fuel installations were, he continued, air-swept, and he illustrated by means of a sketch (Fig. B) the barrel of a ball mill, there being a separator at the outlet. Air was swept through the mill and separator, and any over-size coal which might be pulled through with the air stream was separated and taken back to the mill automatically. Even as recently as ten years ago, he said, the ball mill was such that it could not be used in pulverised-fuel installations, because of its very high power-consumption; its development was due to the fact that by air sweeping one could get the coal away from the mill as it was ground. Previously the coal had remained in the mill for an unnecessarily long time; there was a screen at the end of the mill, and the coal had to work its way slowly through that screen. The result was that an enormous amount of tailings which were unnecessarily fine for operation were left in the mill.

As to fineness of grinding, he said that a pulverised coal (from an average mill, either of the ring-roll or ball type) which would leave no residue on 60 mesh would pass to the extent of about 80 per cent. through 200 mesh. With such a fuel, 95 per cent. of all metallurgical applications would be successful. It was important to specify, however, that the material must be the product of a grinding mill, because a coal pulverised in an impact mill, and which

would leave no residue on 60 mesh, would probably leave a considerable residue on 100 mesh.

The cost of pulverising anthracite was about 25 per cent. more than the cost of pulverising ordinary bituminous coals, but he believed that 140 deg. greater heat was obtained from anthracite than from the ordinary bituminous coals. The first mills used to pulverise the coal for the Sesci furnace were a failure; they were of the impact type. At one British works they used a compound mill, but he believed they would adopt a ball mill, and there was no doubt that that was the right thing to do.

He disagreed with the suggestion that he had contradicted himself when discussing the central circulating system *versus* the single-pipe unit system. He illustrated his point by means of the sketches (Fig. C), and said that where there was a single supply pipe from a feeder he did not claim that there was equal distribution of air and fuel in two burners, but where there were two burners feeding one combustion chamber, the combustion chamber served as a compensating device and balanced out the inequalities. With the circulating system, where there was a ring main supply, there was a stream of fuel and air which was definite and uniform; for every 1 lb. of coal circulating there was 50 or 60 cub. ft. of air, and the proportions remained constant, so that the furnaces supplied from the main always received air and coal in the proper ratio. Equality of distribution was maintained by means of baffles, as shown in Fig. C. The patents in respect of this method of distribution had expired, and it was installed in very many types of works; in one steel plant a ring main served 166 furnaces of different types.

In a ring main, of course, the heavier particles of coal would go to the bottom of the section of the pipes, whilst the lighter particles of coal, and the air, would be at the top, so that, unless precautions were taken to prevent it, the first burners fed from the mains would receive all the over-size particles and the last burners would receive the best of the fines. Therefore, a baffle

was inserted in the pipeline for each burner, and ensured a supply of a fairly uniform mixture of coal and air to each burner. There was also a control and cut-off valve. A baffle was altered only when a furnace was put on or put off; it could be adjusted to give a greater or lesser mixture.

Mr. Gardom asked whether, when a baffle was altered, all the other baffles on a ring main would also have to be altered.

Mr. Boon replied that that was not the case, an alteration being made only when a furnace was started and when it was stopped. The purpose of the baffles was to secure uniformity of the mixture flowing through the pipe, the quantity flowing through was the same always.

Mr. W. B. Lake (Hon. Treasurer of the Institute) asked if the baffle extended right across the section of the pipe.

Mr. Boon replied that it extended vertically upwards from the bottom of the section of the horizontal pipe, but did not extend right to the top.

Mr. Lake said he had asked the question because, if the baffle did extend right across the pipe, it would choke the pipe.

Mr. Wesley Lambert, C.B.E. (Past-President of the Institute), asked if there were in existence an installation using pulverised fuel for melting non-ferrous metals in the open-hearth furnace.

Mr. Boon replied that he had known of three experiments in this connection, two of which were failures, and he believed the third was indifferently successful. Trouble was experienced with the chequers, he believed. So far as he knew, the only furnaces actually running in this country of the reversing regenerative type were three furnaces at the Cordes Dos Company, Newport. They were regenerative and reversing, and had been converted from gas firing. The chequers were opened up from 3 in. on gas to 8 in. on pulverised fuel.

Mr. Lambert asked whether, in these cases, there was direct injection of the pulverised fuel into the melting zone.

Mr. Boon said there was. The air from the chequers came in tangentially. A hole was made in the plates at the large end of the furnace, and the chequers were opened up.

Mr. Lambert said that the pulverised-fuel-fired installations he had seen in operation appeared to have very large combustion chambers.

Mr. Boon agreed that the combustion chambers of boilers were large originally, because we did not really understand the proper ratios to employ or the value of uniformity and fineness of grinding. Normally very few furnaces required alteration when adapted for pulverised-fuel firing, apart from the small alteration in the bridge and the taking away of the firebars.

Mr. Lambert also suggested that, in view of the very considerable wear on the pulverisers, as mentioned by the lecturer, there must be an appreciable quantity of very finely-divided iron associated with the ground fuel, and he asked whether such iron would be carried over with the fuel into the furnace.

Mr. Boon replied that he had not investigated that problem.

Mr. Lambert recalled Mr. Boon's statement that the power required to drive a ball type of pulveriser when running light was practically the same as when it was actually pulverising fuel, and he asked for comparative figures of the power required to drive, under light and load conditions, the ball type and the other types of pulverisers described by the lecturer.

Mr. Boon replied that it was very detrimental to run a ring-roll grinder or even a ball mill empty of product, because the wear was greater when they were running free than when grinding. The power consumption of the ring-roll mill was less than that of the ball mill, because the ring-roll mill was better balanced, but it was very little less. The average power consumption on a 5-ton ring-roll mill was about 14 kw. per ton; a figure of 9 kw. per ton had been achieved, but it was exceptionally good.

The power consumption on the smaller sizes of ball mill was sometimes as much as 20 kw. per ton, but on the larger sizes it could be reduced to about 12 kw. per ton. He had never seen a ball mill do more than a ring-roll mill for a given power consumption.

A Vote of Thanks.

Mr. A. W. G. Bagshawe proposed a hearty vote of thanks to Mr. Boon for his very fair and straightforward review of the applications of pulverised-fuel firing in the foundry industry.

Mr. V. Delport, seconding, said he had seen several installations of pulverised-fuel-fired plants on the Continent, and particularly in the Ardennes—the French foundry district. One was installed in a relatively small foundry, the owner of which had spent a lot of money on the installation, and seemed very happy with it. In another case, also in the Ardennes, a little trouble had been experienced with the pulverised-plant, but the owners had intended to modify it. He had seen other installations in Italy and in Czecho-Slovakia, and, under the conditions in which they were working, everyone concerned seemed very satisfied with them. There was certainly something in the process, and Mr. Boon's Paper would be very valuable to founders who had problems to solve in connection with it.

The vote of thanks was carried with acclamation.

Mr. Boon, responding, recalled that much trouble had arisen in connection with pulverised-fuel-fired installations when the system was first applied, but as the result of the experience gained since that time, there were very little teething troubles with the later plants. The men seemed to like the system and were working the plants admirably. With melting furnaces particularly, there was not a single trouble as a rule; the men had to nurse them for a week or two, of course, but after that the furnaces had worked splendidly.

London and Lancashire Branches.

ITALIAN STEEL FOUNDRY PRACTICE.

By Dr. Ing. Guido Vanzetti (Member).

The story is told that when Henry IV of France made his entry into the City of Rouen, the Governor, coming out to meet him, began his welcome with the following words: "Sire, we should have liked to fire a salute of guns to celebrate this memorable occasion, but several reasons prevented us from doing so. The first is that we have no guns; the second . . ." "Well, we will dispense with the others," broke in Henry IV, "the first is enough."

When I was invited to give a lecture before the London Branch and Lancashire Branch of the Institute of British Foundrymen, I must confess that with so many reasons which tended to dissuade me from accepting, the story of Henry IV crossed my mind. My limited knowledge of English, my inexperience in the matter of lectures, the lack of time in which to make a proper preparation which would allow me to present a Paper of a purely technical character, were all causes one of which alone would have been enough to make me give up the idea. However, there was then one motive which made me change my mind. The enthusiasm with which our British friends expressed themselves with regard to the visit to our country on the occasion of the Foundry Congress caused me to think that I could do like Mahomet, who went to the mountain since the mountain would not come to him, and I should be able to tell my British friends who did not take part in the Congress in Italy what they would have seen had they made the journey and been present.

Moreover, I think that even for those who were at the last Congress I can bring some additional information. They saw our sun, our sky, our mountains, our sea. They saw the masterpieces of Italian art; they kissed the Pope's ring; they heard the words of Mussolini. Perhaps that which they saw least of in Italy were the foundries. Now it is I who will try to outline the conditions under which the foundry industry is being carried on in Italy; I shall limit myself to the steel foundries, in which I am particularly interested.

An Ancient Industry.

Until a few years ago the Italian steel industry had the position in the world of a fallen noble—really a fallen noble and not a baby in swaddling clothes, because, as a matter of fact, in order to give the history of the iron industry in Italy it would be necessary to go back over two thousand years. It is, in fact, asserted that, during the war of Troy, the arms were made of iron obtained from ore from the island of Elba. But during the course of time it happened that our country had alternate periods of great splendour and decadence, and during the latter many traces of past civilisation disappeared. In fact, it happens that even to-day things are invented which have been merely forgotten (such as anchor ball-bearings and bronze taps as seen on the ships of Caligola found in the lake of Nemi). As far as Italy is concerned, we can begin to speak of the steel industry from 1870, when in place of the first Bessemer already at work for some years past, we installed the first open-hearth furnace.

Whilst the production of pig-iron underwent a stoppage towards 1890 on account of foreign competition and the insufficient yield of the charcoal blast furnaces, the steel industry developed rapidly precisely by reason of the installations of open-hearths.

Steel Production.

The production of steel ingots and castings rose from 4,000 tons per annum during the

period 1881-85 to 123,000 tons in 1901 and 714,000 tons in 1910. In this latter period the first "Stassano" electric furnaces made their appearance. They were, in the first place, meant for the direct conversion of iron ore into steel and to eliminate the passages through the pig-iron stage, which seemed a technical absurdity. The extension of the electric furnace for the production of steel in Italy had its greatest impulse during the war period on account of the absence of coal in our country and the difficulties of obtaining supplies in war-time. The total production of steel in Italy reached its highest point in 1929 and exceeded 2,000,000 tons.

From authentic figures it is possible to follow the course of the production of steel *castings* from 1904 onwards. The first maximum point coincided with the period of the war in Lybia, whereas the absolute maximum was reached in 1918; this high point was never again reached, not even in 1929, which was the record year for Italy for the total production of steel and of pig-iron.

TABLE I.—*Percentage of World Production of Electric Steel.*

United States	53.6
Italy	16.2
Germany	10.9
France	7.2
Great Britain	5.6
Sweden	3.7
Others	2.8

Of late years, the level of the annual production of steel castings was slightly more than 50,000 tons. There was a slight increase in 1925 and 1930, although in the latter year the large steelworks and rolling mills, etc., were already passing through a crisis. This increase was essentially due to large orders for the State railways which, together with those for the Royal Navy, take up the greater part of the production of steel castings. In 1931 it was inevitable that this industry also should suffer a contraction, however, within relatively modest limits.

Plant Available.

On examining the capacity of the plants for the production of steel in Italy, it is difficult to make a clear distinction between those relating to ingots and those for castings. There are, in all, 49 steelworks in Italy, ten of which produce castings exclusively. But these latter have a negligible capacity and a very small production of castings as compared with the capacity and production of castings of the large steelworks. There are, therefore, about a score of foundries in Italy which produce steel castings.

There are, for the total production of steel, 122 open-hearth furnaces, with an aggregate capacity of 3,844 tons (83 per cent. of the total capacity), 96 electric furnaces with 744 tons capacity (16 per cent. of total), and 8 converters with a capacity of 44 tons (1 per cent. of total). An idea of the development of the electric furnace in Italy may be gained from the fact that in 1925, whereas the United States were at the head of the list as regards total steel production (about 50 per cent. of world's output), Italy occupied the eighth place (about 2 per cent. of the world production); in the same year, for the manufacture of steel by the electric furnace, the United States were again at the head of the list and Italy was second. Table I shows the relative production of the various countries. Thus, whilst to-day Italy holds the second position in the world for the production of electric steel, it has the first place when comparing production with the relative total.

If we now turn to the particular sphere of steel castings, the percentage of electric steel in Italy is so large that it may be said that to-day in my country, almost all castings are made from electric steel. The types of electric furnaces mostly in use in Italy are "Heroults," then follow "Fiats," "Electrometals," the old "Stassanos," the "Tagliaferris" and the "Brown-Boveris."

Superiority of the Electric Furnace.

I will now attempt to demonstrate the reasons why, all over the world and especially in Italy, the electric-furnace process has developed so extensively. A first consideration of a general nature could be that the electric furnace made its appearance after the converter, and the sole fact that this latter has been supplanted by the former would go to show that those who have had the possibility of making a comparison direct between the two systems, have had no hesitation in making their choice, whilst those who have remained faithful to the converter practically never had a chance of making the comparison.

On the other hand, I know perfectly well that there are eminent founders, many of whom have not forsaken the old converter and who may answer by telling me that during these several years of experience, also under the pressure of the competition of the electric furnace, they have been able to improve their system of manufacture in such a way as to obtain results, of which there was not the slightest conception at the time when the new process by electric furnace began to replace the converter; and the steel castings turned out by the British foundries would not have the fame of being among the best in the world had they not achieved this point of perfection in the use of the converter. At the same time, I do not overlook how adept you are in the use of the electric furnace; you must know that the person who came into our own particular foundry to install our "Electrometals" and to instruct us in its running was actually an Englishman, Mr. V. C. Faulkner, your Past-President.

Economic Advantages.

From the economic point of view, the electric furnace found its ideal sphere and took precedence over the other systems, principally by reason of the fact that it allows the utilisation of hydro-electrical energy, in which Italy is rich, in place of coal which Italy has to import from coal is delivered to the various furnaces by

has the special advantage, so far as we are concerned, of being an all-scrap process.

Examination of this characteristic of the Italian steel industry and its various causes would lead me away from my subject, because it would be necessary, from a more general point of view, to consider the conditions under which the main Italian steel industry is carried on rather than the steel foundry. The relative scarcity of iron ore in Italy, the absence of coal, the greater consumption of fuel in a complete cycle of operations starting from the iron ore, and the cost of transport, are all points which influenced the disappearance of the Bessemer from the steelworks in favour of the open hearth particularly for the production of ingots, and in favour of the electric furnace for the production of castings. It must also be borne in mind that whereas pig-iron is protected by an import duty (which has a bearing on the prices of the national product) scrap is free from duty.

Cost of Electricity.

The cost of electrical energy is very variable from one district to another. Of course, along the Alps and along the Apennines, in the neighbourhood of the sources of energy, it is lowest. There are a few works for the production of ferro-alloys which consume what is called seasonal power, and for this they pay only from 2 to 3 centesimi and even less per kilowatt-hour (about one-tenth of a penny). In Milan the cost is pretty high. The terms of the contract between my foundry and the suppliers of power enunciate that the power consumed must be charged at the end of each month and that two separate invoices are to be made out, one for demand charge and one for energy charge. The demand charge relates to the thirty minutes of maximum demand during the month, costing 30 lire per kw.-hr. (8s. 6d. to 9s.), whilst the energy charge is rated at about 7 centesimi per kw.-hr. consumption during the summer and 13 centesimi during the winter

(respectively about one farthing and one half-penny). The winter rate lasts about four months, November to February, and the summer tariff is applied for the rest of the year. Taking into consideration both the demand and energy charge, this tariff works out at an annual average charge or cost of almost 18 centesimi (just under three farthings).

Raw Material Costs.

If we consider that ordinary steel scrap (second grade) costs about 180 lire (£2 12s.) per ton, delivered at our works, coal for the open hearth about 130 lire (£1 17s.) per ton, coke about 190 lire (£2 14s.) and hematite pig-iron about 400 lire (about £5 18s.) and without going deeply into a detailed analysis of cost, it will be seen that the conditions in our country with regard to supplies of raw material are very much different from those obtaining elsewhere and this is sufficient to justify a different orientation being taken in the matter of manufacturing processes.

A Comparison with the Bessemer.

As regards thermal yield, although that of the converter is high, it is however understood that it is below that of the electric furnace when one takes into consideration that over 30 per cent. (according to Osann) of the heat produced by the oxidation of the bath and by the formation of slag is lost by heating the nitrogen blown into the converter with the air. The possibility might perhaps be studied, in the case of a very low price for the oxygen, meaning where it can be obtained as a by-product in the manufacture of nitrate products, of blowing oxygen alone into the converter.

If we take into consideration the melting loss, the converter has under this heading, a great disadvantage in comparison with the other processes. According to Lister, the loss is between 20 and 30 per cent. comprising both cupola and converter losses. According to our experience, out of 100 kgs. of metal charged

in the cupola, about 95 kgs. of molten iron are obtained, and from the converter we could only with difficulty obtain about 75 kgs. of steel.

The heating of the bath is produced by a very costly fuel, *i.e.*, pig-iron, comprising Fe, C, Si, Mn, particularly Si and Mn whose presence in the iron increases its cost.

Of course, much better results can be achieved. Some assert that, under favourable conditions, the loss, comprising cupola and converter, can be reduced to about 12 per cent. I think, however, that these are exceptionally favourable results and only obtainable in isolated cases. Just as when Americans state that with their acid-lined electric furnaces they have a power consumption of 500 kw.-hr. per ton of produced metal, I think they are not speaking of a long period of work but rather of just a snap test, during which none of those incidents has occurred which have called for a calculation of a supplementary consumption of from 20 to 25 per cent. In any case, melting loss is undoubtedly lower with the electric furnace, being from 3 to 5 per cent.

If we take into consideration exclusively the running of the foundry and the adaptability of the furnace to the quantity requirements of the production, it will be seen that actually the small converter has a superiority over the other systems. The possibility of obtaining small quantities of steel at short intervals of time and being in a position to stop when required, is the ideal condition for a foundry. With two cupolas, each with an output capacity of about 6 tons per hr. of iron, and two converters of 1 ton each, it is possible to obtain the smallest castings, in competition with malleable iron, up to 30 tons. Further, the possibility of rapid production by the converter has the advantage of being able to reduce the furnace capacity, installation and running costs. From this point of view the open hearth is the worst adapted for a foundry of the jobbing-work type where castings are produced in all sizes and in all quantities.

The Position of the Open Hearth.

The possibilities of the open hearth for such foundries are limited by various considerations, which originate from the fact that an operation lasts several hours, and that it is necessary to employ quickly at the moment of the pouring a quantity of metal which must be uniform and equivalent to the capacity of the furnace. It is not easy to bott up the furnace before having completely emptied it, even in the case of an acid furnace, and it is well-nigh impossible in the case of a basic furnace. Really, only tilting open hearths give the possibility of drawing off just the required quantity of metal in a ladle, but the practical realisation of this method presents some difficulties on account of the cost of installation and the task of procuring good joints at the gas and air ports.

The fact of having to utilise quickly at a given moment the whole of the steel produced is a serious inconvenience, because, as it cannot be raised to a very high temperature by the open hearth, it cannot be long kept in the ladle, nor is it always possible to utilise it by a special organisation of quick distribution with shanks. From this we gather that where there is not a considerable tonnage of large castings to be poured the capacity of the open hearth should be rather small (from 3 to 8 tons). And as the open hearth, in order to be operated under good working conditions, should be continuous, the capacity of the furnace must be limited to the *minimum* output of castings; other furnaces (converters or electric furnaces) for the purpose will produce any variable supplementary tonnage required. However, in such conditions the consumption of fuel is high, as, for small open hearths, the quantity of coal loaded into the gas-producer reached 40 to 50 per cent. of the weight of the metal produced.

As regards cost of installation for a certain capacity, the electric furnace (furnace, transformers, etc.) varies between one-half and two-thirds (according to Levasseur) of the cost of

installation of an open-hearth (furnace, gas-producer, chimney, foundations, etc.).

The electric furnace, although it may not have the elasticity of running of the converter, can be very well adapted to any production both as regards quantity and quality. In fact, the electric furnace is very adaptable to any quality of metal. A heat of ordinary carbon steel can be followed by a white iron or grey iron or special steel heat. It can also be run more economically than the converter, provided the installation in connection with the capacity of the furnace and the contract for electric power have been well studied and managed.

Acid or Basic?

The choice of the acid or basic furnace will depend on the type of product which it is required to obtain. In any case it may be observed that for any quality of final product, the purer the raw material is and consequently the more costly, the less time the operations take and the less current is consumed and the lower is the cost of refractories. It is therefore a case of making a compromise between the two tendencies. Even in the case where the scrap is inferior it may be necessary to use the basic furnace for such scrap, also it might be advisable to use a small acid furnace for remelting domestic scrap which, having been obtained previously from a basic furnace is, of course, of good quality. This is the system which we are now applying in our own foundry. The choice of the capacity of the furnace is of great importance with regard to the rational running of an electric furnace.

Choice of Electric Furnace.

Electric furnaces for foundries are generally of a capacity between $\frac{1}{2}$ ton and 6 tons. Within the limits allowed by production requirements, it is advisable to adhere to small units. It is better eventually to run sometimes with the furnace overcharged rather than under-burdened. Although on the one hand the large furnace

offers a better utilisation of heat, taking everything into account the small one can be run more economically; it will require a smaller quantity of maximum demand power, thus giving the possibility of obtaining better contract terms from the supplier; it requires less labour; it works more rapidly with small lots, adapting itself better to foundry requirements and approaching more in this sense the working of the converter. Floor space, cost of cranes, etc., all the accessory equipment for furnaces and the number of boxes employed are all points in favour of the electric furnace of the small-capacity type.

Even the running of the electric furnace, in order to be carried out under the best conditions, should be continuous. But of course these conditions depend on the contract for power. In cases where it is possible to have power at special rates during the slack periods of one or two hours in the day, it would be well to examine the possibility of running intermittently, the use of a basic or acid lining, seeing that it entails a more or less longer duration of the manufacturing process, and the advantage of running the duplex system. In this case, during the stoppage period, having charged the furnace immediately after the last heat, it would pay to keep the furnace hot by an oil burner placed at one of the doors. In our own foundry we have found that we can more simply make the charge of scrap and hermetically seal all the apertures of the furnace, doors and around the electrodes, with clay, in such a manner that all the heat of the lining is diffused in the charge, diminishing the loss by radiation, which is proportional to the fourth power of the difference of the temperature between the outside and the inside.

Another very important point of view in the comparison between the various systems of manufacture of steel for castings is that of the examination of the product—its chemical and physical properties or its metallographical and foundry properties.

The mechanical properties of electric steel are, without doubt, the best in regard to the dynamic and static tests. When we take into consideration formulæ, as for instance, tensile strength plus twice the elongation percentage, by which steels are often judged, the highest points are reached in the case of electric steels on account of their purity, which can approximate to that of crucible steel. It is evident that it is insufficient for a steel to be produced in an electric furnace in order that it should be of superior quality. It must also have been properly prepared, but this not invariably the case. On account of the flexibility of the electric furnace, in some cases it seems to have been installed because it appeared to be easy to run in a foundry, and without any of the principles of metallurgy being applied by inexperienced founders and without laboratory control. Lister says that the best electric steel is almost equal in quality to the best acid open-hearth and much superior to basic, but that bad electric steel is much worse than the worst products of either.

Stricter Specifications.

One of the reasons of the popularity of the electric furnace was precisely that of quality. During the past few years specifications for steel castings have been tightened. This has been a point in favour of electric furnace operations. Then, too, there has been a change from cast iron to steel of many types of small castings, especially for motor-car work. These factors made it more difficult for the open-hearth shops, where it is impossible to obtain the high temperature reached in electric furnaces, and, on the other hand, converter shops with which one cannot produce steel of the purity of the electric steel.

The running of the converter has been defined as "a barbaric operation which causes a veritable emulsion of slag-oxides-dissolved gas, in the steel." All these substances are to be found in more or less considerable proportions in the castings, or in the form of solid inclusions, or

blow-holes. And this always happens in spite of the fact of obtaining a great reduction of the disadvantage by allowing the steel obtained from the converter to be killed in the ladle or in a mixer. Benedicks points out that as converter steel is more fluid than other steels it becomes easier to eliminate its impurities. A greater fluidity carries with it a greater "rising velocity." But to this one can reply that, even admitting this greater fluidity of converter steel, electric-furnace steel comes out better logically as it is purer, because the impurities to be eliminated are in a much smaller quantity. On account of the different conditions under which the process of manufacture takes place, seeing the absence of any kind of gaseous matter blown into the furnace, the metal can be killed, readily assuring sound castings. In relation to the converter, the electric furnace offers all the advantages of the open hearth source of heat independent of the internal reactions, therefore wider liberty in conducting operations and option of prolonging the refining period until the attainment of steel of the exact properties required, with the possibility of controlling the analysis at any moment.

The deoxidation of the metal comes about under very satisfactory conditions because it is easy to maintain a non-oxidising atmosphere, and, further, a steel is obtained which contains very little nitrogen and hydrogen. The temperature is easily regulated and is always under exact control, and can reach any degree practically desired. There is the possibility of liquefying very refractory slag. Electric steel, being of a higher quality, can be forged more easily. According to Levasseur electric steel is less susceptible to deformation in quenching.

Electric steel is less injured by overheating than other steels. It has a wider range of heat-treatment and, according to Matthews, will stand variations in forging, following treatment without injury. Considering the chemical properties of the steel, it may be observed that with

the acid converter (which is generally used in the foundry because the basic ones do not give a steel hot and fluid enough to pour castings) it is not possible to eliminate sulphur and phosphorus, thus demanding a very pure metal from the cupola. It is thus not possible to utilise all the scrap produced, because, on account of the large melting loss, there arises a concentration of sulphur and phosphorus.

Sulphur and Phosphorus in Bessemer Steel.

Even the method of eliminating phosphorus by treating the steel with lime in a ladle with a basic or neutral lining, immediately after the blowing and before the deoxidation and recarburising additions is not very efficacious, because the quantity of phosphorus which is thus eliminated, is very limited. Further, there is produced a cooling of the bath, and the recarburation with the iron coming from the cupola again increases, although in a smaller proportion, the phosphorus content. In any case it may be understood that the possibility of making additions in the furnace itself, as can be done with the electric process rather than in the ladle, increases the probability of thorough assimilation, diffusion and homogeneity.

As for the sulphur, with the electric furnace there is no contamination by this caused by means of heating, as happens with the cupola and with the open hearth; there is, instead, the means of desulphurising completely.

It has been attempted to reduce the final sulphur in converter steel by introducing less sulphur in the melting of the iron and by eliminating it before transforming the iron into steel. Stoughton studied a method of partial heating of the cupola by oil combustion, decreasing the consumption of coke and the consequent inclusion of sulphur. Or the molten iron coming from the cupola can be treated with soda ash in a neutral-lined ladle, or, better still, in a special forehearth (Scharlibbe system) arranged in such a way that the acid slag does

not come into contact with the additions. In this case the desulphurisation could not be brought about because the affinity of the soda for silicon is greater than for the sulphur. With a proportion of alkali corresponding to ½ per cent. of the weight of the iron, there can be obtained a reduction of 50 per cent. in the sulphur content. But, of course, this system is not economic, and offers the disadvantage shown in our foundry of the rapid destruction of the acid lining of the converter in the case where any basic slag might come into contact with the iron.

Foundry Properties of Electric Steel.

The foundry properties of electric steel are by far the most important, but unfortunately it is very difficult to represent them in figures. When in the same foundry, there are utilised steels for castings produced by the electric furnace and by other processes (not taking into consideration the crucible), it can be seen that the first give incomparably fewer cracks, blow-holes, etc. An interesting comparison* has been drawn between the converter and the electric furnace practically obtained by the running at the same time of the two systems in the Taylor-Wharton Iron and Steel Works. The results were in favour of the electric furnace. The rejections resulting from the converter steel on account of cracks were equally present even when the sulphur content was less than in the castings poured with electric steel and turned out perfectly sound.

It is generally recognised that the percentage of rejections of castings with the electric furnace is much lower.

According to Levasseur the heads of castings poured with electric steel can be reduced without disadvantage. It is possible to obtain thin castings or those presenting thick and thin sections more easily than with the other processes.

Life of Electric Steel.

Another important point to be considered is the life of the metal. Although this may have

* "Foundry," February 1, 1920.

been sufficiently studied with reference to iron, the case is different as regards steel. Further, the comparison of the life of steel obtained by the various processes is very much discussed, but it has not yet been well defined. Often "life" is confused with that of temperature. It is sometimes stated that steel obtained by the basic electric furnace is less fluid than that obtained by the acid process, but personal opinion is that it is more the case that, with an acid furnace, higher temperatures are attainable than with the basic furnace, due to the absence of a heavy slag and to a better resistance to the heat of the acid hearth. On the other hand, there does seem to be a certain difference between the actual fluidity of the two kinds of metal.

I therefore find it rather debatable to assert that steel obtained with the electric furnace is less fluid than that obtained with the converter, as some of the upholders of this latter process sustain. But, actually, the fact that converter castings are more liable to defects than others (mainly the characteristic defects of metals poured too hot—cavities, cracks, oxidation, etc.) shows that the greater life of converter steel is due exclusively to the higher temperature at which it is poured.

With regard to life of the metal, even a direct comparison of the two methods would only be of relative importance unless account were taken of all the different variables which are called into play in the life. I say life, and not fluidity, because whilst the latter indicates an intrinsic quality of the metal, the former varies also with the change of extraneous conditions as regards the metal. Portevin has defined coulabilité or life as being the faculty which molten metals have of filling more or less completely a mould, and it may be said that the life depends on the characteristics of the metal (temperature, chemical composition), of the mould (surface conditions, moisture, temperature, permeability, etc.) and on the manner in which the metal is poured into the mould.

The factor which influences most profoundly the life of steel is the temperature; for reasons already shown with regard to the disadvantages arising from a steel which is too hot, to which is to be added the danger of the fusing of the moulding sand, it is, above all, necessary to try to obtain as low a minimum ratio point as possible of temperature life. With regard to the influence of the composition of the metal on the life, it is ascertained by practice that an oxidised steel is less fluid than a non-oxidised steel.

It is generally recognised that for iron the chemical composition of the metal has an influence on the fluidity. For steel, Mr. Gabino, of the Fiat works, in a Paper presented to the Italian Foundry Congress, states that, as a consequence of various experiences met with in the study of the life of steel, he found no pronounced influence of the chemical composition (within the limits of normal variations) on the life. He only observes a large increase of fluidity of the bath after the addition of ferro-silicon. This fact, which contrasts with the observations of Benedicks, probably arises from the deoxidising action of the ferro-silicon. Mr. Gabino shows in his Paper, too, in what way the condition of the mould influences the life—greater life is given with dry moulds and less with green-sand moulds. In green sand, with 1 per cent. of dextrin, it is, however, possible to obtain nearly the same results as with dry sand.

Finally, there is considerable importance to be attached to the outflow velocity of the metal into the mould—velocity which is created by the height of the ferro-static loading column and the length of drop of the steel jet; conditions of running the steel into the mould as arising from the runner sections; size and shape of the runner bush and the manner in which the metal is poured. We have observed that moulds poured apparently under identical conditions gave us alternately sound castings and short-run castings. This was due to the fact that, pouring with the large bottom-pouring

ladle with different openings of the stopper, the runner bush was not continually full. Even the formation of a vortex in a circular feed box makes its influence felt, because the swirling motion produces a load loss. This disadvantage can be avoided by using an oval pouring basin.

From all these points which have been discussed and which have influence upon the life of steel, it can be seen that it is difficult to establish with certainty by which method of manufacture a greater fluidity of metal can be obtained. In fact, it is difficult to render constant all the variables of the problem. And when we come to think that up to a short time ago the optical instruments for the reading of the temperature were liable to errors up to tens of degrees, and that a difference in temperature of such magnitudes has considerable influence upon the viscosity of the metal, it will be understood in what measure the comparisons between the results obtained with the various methods corresponded to a personal statement or opinion rather than to a comparison of figures.

To finish this short comparative study of the various methods of manufacturing steel, it can be concluded that when considering open hearths and converters, each of these present a series of advantages and disadvantages which cause the preference to be given to one process or the other according to the particular case as regards use. As for the electric furnace, it is evident that, when well run, it embodies such industrial advantages, technical or economic, which are of such importance that its superiority becomes beyond discussion except in cases where the price of electrical energy might be too high.

Up to now I have made no mention of electric-induction furnaces and pulverised-coal-fired rotary furnaces. The main reason for this is that I do not know sufficient of the subjects to be able to discuss them with authority.

In our own foundry we have thoroughly examined the advantage of using an induction furnace for the manufacture of special steels,

but we halted on account of the following considerations:—(1) Extremely high cost of installation and (2) the last word has not yet been said regarding the practical realisation of the principles on which it is based: voltage—number of periods—construction of condensers—construction of acid and, above all, basic lining; (3) difficulty of refining because slag is colder than metal, being a non-conductor. On the other hand, there are certain advantages:—(1) No alteration in the bath on account of the presence of electrodes and air (it being possible to close the furnace—in the laboratories melting is done even *in vacuo*)—and (2) a saving of current.

Starting out with raw material of the best quality, anything can be done that may be required. It may be possible that anybody who has been obliged to purchase one of these furnaces for high quality steel, may be able to use it also for the production of ordinary carbon steel. To-day the study and the production of high tensile cast iron is being extended: the induction furnace can very well serve for the purpose just as for any kind of special steel. Its use is ideal in the case of remelting special steel scrap.

In summing up, we foresee that in the course of time we shall end by deciding on the purchase of one of these furnaces, once the disadvantages explained have been removed or reduced and the consumption of special steels becomes such as to warrant the installation cost.

The Brackelsberg and the Sesci acid-lined rotary furnaces, according to some, have an ensured future in the steel foundries. Whilst in the open hearth, the temperature of the process is limited by the refractoriness of the roof, in this type of furnace, on account of slow rotation, the roof is changing at every moment, and the bricks which, as a roof, at certain moments are at the highest temperature, soon after cool, giving up their heat to the bath, when acting as bottom. Further, for steel, all temperatures practically necessary are reached by preheating

the combustion air by means of a heat regenerator. The latest report which I know of with regard to the Brackelsberg rotary furnace used for steel, is that of Bardenheuer, who states that he has attained very good results both as regards economy in running and quality of the metal obtained. It was very good from all points of view—mechanically, chemically and for foundry properties.

The Vanzetti Foundry.

I now wish to give you a brief idea of the system of steel manufacture used in our Milan foundry. It was established in 1888 for the object of producing light steel castings with the small Robert converter, and the foundry worked for several years with no other apparatus. About 1895, when the increased number of orders made continuous working possible, two small open-hearth furnaces of 3 and 4 tons respectively were installed, and later a third one of 7 tons. In 1910 electric furnaces were introduced—at first three Stassano furnaces of 1 ton each; afterwards two Electro Metals furnaces of 3 tons were built. During the war several more electric furnaces of our own type were installed. At present the steel foundry has two converters, 2 open-hearths, five electric furnaces, but is mostly served by one or two electric furnaces at a time during this period of depression. Already in 1894 we began the production of large castings, using the converter alone. At the Milan works, two Robert converters of about one ton each were installed with two cupolas each capable of melting six tons of iron per hour. There is one piston blowing-engine, driven by electricity, capable of delivering 90 cub. metres of air per min. at a pressure of 40 c. of mercury.

In the early years of the operation of the plant, castings of about two tons maximum were produced, working with one converter only. In 1894 it was believed we could accept the order for the two supporting brackets for the screws

of H.M.S. Marco Polo. Each casting weighed 6 tons net, or about 10 tons gross. To avoid the chance of short-running in making the first one, it was calculated that 12 tons of molten metal would be necessary.

At that time the foundry did not possess a travelling crane of more than 6 tons capacity, so that it was necessary to devise a mixer mounted on two standards into which to pour the steel. The casting of the first bracket was a complete success, insomuch that, for the second, it was decided to prepare only 8 tons of steel. The additional 2 tons necessary for the feeding-head were blown afterwards and poured direct into the runner forming the feeding-head. The two cupolas were kept in continuous operation, and the two converters were worked alternately, the blowing engine having to run continuously.

The result was so satisfactory that the firm did not then hesitate to accept orders for much larger castings. Most of the stems, stern frames and rudder frames of Italian merchant and warships were cast by the method described. On account of its convenience, the system in general has been retained to the present day.

Some brief notes on the present method of procedure may be given here.

The Robert foundry consists of three bays, each 10 metres wide. At the end of the central bay are placed the two cupolas. A ladle for receiving the molten metal is run between the two cupolas, and when filled is lifted by a special windlass to a height sufficient to enable it to tip the metal into either one or two sheet-iron troughs which can be slewed on a swivel. Through these troughs it flows into the converters. These latter are tilted by motors, but hand gear is also provided. A travelling crane ranging the whole length of the bay brings the steel ladle into position to receive the charge from the converters, and pour it into the mixers, which are suitably placed in the foundry for pouring the contents direct into the mould.

It will be understood that it is necessary to have the metal very hot and to work very rapidly, other considerations of economy having to be sacrificed to these two conditions. On this account, a higher proportion of pig than of steel scrap must be charged into the cupola, the quantity of coke for melting is increased, and moreover the converters are furnished with eight instead of five tuyeres. A higher air pressure is thus required for blowing the converters, and this increases the loss in blowing.

It was customary to send the first heats from each converter to the foundry for ordinary castings, then, when a sufficiently high temperature was reached, the filling of the mixer was begun.

We have noticed that the chemical composition and mechanical properties of steel have improved after remaining a long time in the mixer. The steel as it comes from the converters contains considerable quantities of oxides and slag in suspension. During the time it remains in the mixer these impurities separate partly by liquation and partly by the reactions produced by the manganese and silicon content in the steel. It is precisely on account of these reactions that it is possible to keep the bath hot into the mixer for several hours.

The converter, providing a means for obtaining at short intervals a very hot steel in small and frequent quantities for feeding the head, reduces very considerably the volume and weight which it is necessary to give to the feeding-head.

We have been successful, with this system, in pouring castings up to 30 tons using two mixers, and up to 50 tons using also the steel coming from the other furnaces which was poured together with that of the mixers. Recently we had to pour a certain number of castings of 30 tons, and we found it more economical to use the first heats of the converter, still rather cool, for charging the electric furnaces instead of for pouring castings. The electric furnaces ran contemporaneously with the converter. Our charges into the cupola are 50 per cent. hematite iron

and 50 per cent. steel scrap, the scrap consisting principally of springs with 1.5 per cent. of silicon.

The two open-hearths are in good working order, but for several years they have not been running. They are being held in reserve awaiting better times, which makes our position secure in case of any subsequent exceptional increases of cost of electrical energy.

Electric Furnace Plant.

Further, we possess three electric arc furnaces, Electro Metals type, basic lined, of 3 tons each, with automatic regulation (Brown Boveri). The main advantage of this kind of electro-hydraulic regulator consists of its great sensitivity and the fact that the electrodes drop only by their own weight, and this avoids all risk of breakage. The electrical energy, which is supplied to us in three-phase form at a tension of 22,500 volts, is transformed with a Scott connection by means of two monophase transformers.

In normal working, the two electrodes are equally loaded, and with the Scott system of primary connections, equal loading of the three primary phases is assured. This is a most important feature, and is much appreciated by power station engineers. Metallurgically, the two-phase furnace offers the greatest possible advantages. The magnetic field set up by the combination of the two arcs and the conducting hearth imparts a circulation to the molten charge, partly in a horizontal and partly in a vertical plane. This results in bringing all portions of the liquid charge into successive contact with the highly-heated refining slag, and by dissipating the heat from directly under the arcs reduces radiation on to the roof and walls.

Further, this equalisation of temperature between the upper and lower portions of the charge facilitates the melting of alloy additions used for special steel manufacture. Some of these alloys, such as Fe-V, Fe-W and Ni, are very much denser than steel, and have high melting points. Consequently, when they are

thrown into the steel, they at once sink and lie on the bottom of the furnace. The circulation of the charge in the two-phase furnace brings the pieces of alloy constantly in contact with fresh hot metal from the surface, so that they become rapidly melted and evenly disseminated throughout the charge.

Another noticeable metallurgical feature is the regularity with which the final amount of carbon in the steel can be controlled. This is mainly due to the fact that the two arcs are absolutely independent of one another, so that there is no possibility of one electrode dipping into the metal, and so adding carbon to the charge.

The capacity of the furnaces is 1,000 k.v.a. (two transformers of 500). The secondary windings can be varied to give 90, 100, 110 volts by means of a regulating switch (commutator) placed on the regulation switchboard of the furnaces. The regulation permits, according to the operations which are being carried out, a variation of the power absorbed by the furnace of between 500 and 1,000 kw.

The average consumption of electrical energy for the production of ordinary steel, perfectly dephosphorised, fluctuates between 800 and 850 kw.-hr. per ton of scrap charged. The consumption of graphite electrodes (Plania Werke Siemens) is 3.8 to 4 kg. per ton charged. The time employed for each heat is from 3 to 3¼ hrs., excluding the charging operations and any serious repairs.

When the scrap purchased on the market is so low in phosphorus and sulphur as to be able to avoid the period of dephosphorisation with consequent slagging off, the operation consists of a simple melting of the material under a reducing slag, and in this way we succeed in obtaining very good steel in 2 hrs. (exclusive of the time required for charging and any serious repairs).

We recently installed, essentially for the purpose of producing special steel and in order to be able to utilise our own ordinary carbon steel

scrap, two Brown-Boveri electric arc furnaces of 1,200 kg. each. These furnaces have not yet begun working, therefore I cannot tell you much about their characteristics. They are served by a single transformer of 600 k.v.a. (transformation ratio 22,500 to 160), so that they can only run one at the time. (In the transformer it is possible to have commutation from the star to the delta connection and *vice versa* on the primary, so that the following secondary voltages can be procured: 58, 70, 81, 92, 100, 120, 140, 160). The variety of voltages available permits of running with acid or basic lining. Each furnace is supplied with a spare shell, so that in case of repairs the shell can be rapidly substituted complete with lining and roof. There is also provision for the possibility of adopting a lining which would reduce the capacity of the furnace to 700 kg. There are three electrodes, whilst the bottom is a non-conductor. The regulation is automatic and of the Brown-Boveri electro-hydraulic type. The guaranteed maximum of consumption with basic lining is from 700 to 750 kw.-hr. per ton charged.

Up to the present we have been pouring our castings up to 3 tons with a 3-ton bottom ladle. The main defects of this system are (1) excessively long duration of the pouring, which implicates a considerable difference in temperature of the metal between the beginning and the end; (2) the stopper will not always stand a very large number of openings and closings to which it is subjected when small castings have to be poured, and (3) the height of the ferrostatic loading column is such as to cause the steel to arrive with a considerable energy, giving rise to erosion in the mould and carrying away with it some sand, traces of which are afterwards found in the castings. We have succeeded in overcoming this difficulty by suspending under the ladle hole a tun-dish lined with magnesite. This tun-dish can be emptied by a workman by turning it like a small hand-ladle on a horizontal axle. The steel jet is broken against the bottom of it and falls into the mould.

We certainly think that the best method in which to eliminate all the difficulties mentioned above is to adopt a system of rapid distribution of the steel with small hand-ladles carried by a monorail and fed by the large bottom-pouring ladle. Unfortunately, however, present conditions do not allow us to carry out these transformations and others which assuredly would bring about a reduction in labour.

We are somewhat in the position of a certain person who, when approached by an inventor who offered him a very complicated machine capable of substituting twenty workmen, replied: "Could you not invent for me a machine which would be capable of bringing in twenty customers?"

The following authorities have been drawn upon in the compilation of this Paper:—

B. Osann ("Lehrbuch der Eisen und Stahlgiesserei"); C. Clausel de Coussergnes ("L'Electrosiderurgie"); A. Ledebuc ("Handbuch der Eisenhüttenkunde"); C. Benedicks and H. Löfquist ("Non-Metallic Inclusions in Iron and Steel"); G. Geiger ("Handbuch der Eisen und Stahlgiesserei"); W. Lister ("Practical Steelmaking"); L. Barton ("Refining Metals Electrically"); A. Levasseur ("L'Electrochimie et l'Electrométallurgie"); F. T. Sisco St. Kriz ("Elektrostahlverfahren"); D. Carnegie et S. C. Gladwyn ("L'Acier, Sa Fabrication, Son Prix de Revient"); R. Lemoine ("La Production de l'Acier de Moulage"); C. Vanzetti ("The Use of Small Converter for the Production of Large Steel Castings"); J. W. Deschamps ("Considérations sur les Avantages et Désavantages Respectifs des Différents Procédés employés dans la Production de l'Acier en Fonderie d'Acier") U. Gabino ("La Colabilità dell' Acciaio"); Annuario dell' Industria Metallurgica Italiana, 1930 (Associazone Nazionale Fascista fra gli Industriali Metallurgici Italiani); P. Bardenheuer ("Das Schmelsen von Stahl auf Sauerem Futter im Brackelsberg-Ofen"); B. Osann ("Lehrbuch der Eisenhüttenkunde").

DISCUSSION.

The Chairman (Mr. H. G. Sommerfield), in welcoming Dr. Vanzetti, said that he promised to become just as brilliant an engineer and as ardent an advocate of metallurgy as his father, Signor Carlo Vanzetti, C.B.E. Dr. Guido Vanzetti had graduated as a Doctor of Engineering in Milan and was a partner with his father in the Milan Steel Foundry, which was one of the largest in Italy. The members of the Institute of British Foundrymen would remember the courtesy, the hospitality and the cordial welcome which he and his father had extended to all visitors, particularly the Britishers, on the occasion of the last International Foundry Congress in Milan. The members of the London Branch were extremely grateful that he had travelled from Italy to England, at a time when the whole of the industries of the world were experiencing difficulty, to give us the benefit of his views, experience and research in the Italian foundry industry.

The Advantages of Tropenas Steel.

Mr. J. Deschamps, after congratulating Dr. Vanzetti on his very interesting Paper, expressed surprise that in his foundry at Milan the cost of producing steel with the surface-blown converters was much higher than the cost of steel obtained from electric furnaces, although the charge for electric current was as high as 0.75d. per unit and the cost of scrap about 52s. per ton. This was probably due to the extraordinarily heavy losses he was obtaining in his conversion, which losses, he had said, were between 20 per cent. and 30 per cent. of the metal charged into the cupola. This was twice as much as was obtained by good modern converter practice. The pressure used by Dr. Vanzetti for blowing his converter was about 40 cm. mercury, which was about 8 lbs. per sq. in.—at least three times greater than it should be. Mr. Deschamps expressed the view that when operating side-blown converters it was best to ignore all indications given by

text-books on the subject, and that whereas the various authors who had dealt with this matter recommended a silicon content of about 2 per cent. in the metal, much better results were obtained if the silicon was about half that amount.

Dr. Vanzetti had made a great point about the ability of the basic lined electric furnace to produce metal with very low sulphur and phosphorus contents. Although Mr. Deschamps was quite prepared to admit that converter steel, even when made under the best possible conditions, could not be made with as low sulphur and phosphorus contents as could be obtained in well-made basic electric furnace steel, it is now possible, by efficient desulphurisation of the metal issuing from the cupola prior to blowing, to obtain steel with a maximum of 0.04 per cent. sulphur even when the cupola charges contain as much as 70 per cent. steel scrap.

Regarding the phosphorus, it was admittedly an impossibility to remove it in the acid converter process, but too much importance was generally given to the presence of this latter impurity in the metal. After all, what mattered most to the foundryman was to obtain steel with the maximum fluidity for a given temperature, or, in other words, the maximum life, as Dr. Vanzetti had pointed out. Mr. Deschamps submitted that well-made converter steel evidenced this quality more than steels made by any other processes. That excellent physical results (unequalled by steel made by any other process) could be obtained had been proved by experience, and in this connection he pointed out that the existing specifications for steel castings were much too lenient and that instead of asking, as the present British standard specification does, for mild steel having a minimum tensile strength of 26 tons per sq. in., coupled with an elongation of 15 per cent. (which characteristics corresponded really to poor metal), we should insist that a minimum tensile strength of 26 tons per sq. in. be accompanied by a minimum elongation of 30 to 35 per

cent.; that in the case of steel for wearing surfaces, where existing specifications ask for 35 tons minimum tensile coupled with a minimum elongation of 10 per cent. and no cold-bend test, we should insist on about twice this elongation and on a cold-bend test of at least 90 deg. without fracture.

He was satisfied that well-made converter steel could meet these more stringent requirements, and he expressed doubts as to the ability of steel made by any other process to equal these results. He championed the much-abused converter steel because he believed that there was still a great future for steel made by that process, the application of which had been considerably improved during the last ten years and which, in addition to its technical advantages, possessed another most important advantage, *i.e.*, cheap cost of manufacture. Many engineers considered that electric steel was the better metal, but he attributed this—to his mind erroneous—opinion to the glamour attached to the word "electric." In conclusion, Mr. Deschamps thanked Dr. Vanzetti again for his interesting statement on the Italian steel industry and expressed the hope that members of the Institute would have a further opportunity in the future to listen to him.

Claims of Electric Steel Supported.

Mr. W. B. Lake (Hon. Treasurer of the Institute and Past-President of the London Branch), in adding his thanks to Dr. Vanzetti for his very able Paper, recalled that some years ago, at a Foundry Convention in America, he had had the great privilege of accompanying Dr. Carlo Vanzetti on visits to a number of steel foundries and discussing with him the very questions which his son had dealt with so ably in the Paper. He was very much impressed by the lecture as a whole because he had felt that Dr. Vanzetti was dealing with realities and had put forward a number of figures which one could believe, for they had corresponded so well with figures he had obtained in actual practice.

Coming to a discussion of the merits of electric and converter steel, Mr. Lake said he felt that in attempting to cross swords with Mr. Deschamps he was attempting a very dangerous task, because he believed Mr. Deschamps had developed the manufacture of converter steel to a point to which few had developed it in this country. At the same time, Mr. Lake could not accept all that Mr. Deschamps had said on this subject, although he must make some allowances. He recalled his experience during the war when running a steel foundry engaged in the making of wheels for automobiles. These castings were particularly liable to hot cracks, and half the product was run from electric furnaces and half out of converter plant. The experience had been that in light and difficult castings there were many more tears and cracks when converter steel was used than when electric steel was used, but it was only fair to say that he had not used the desulphurising process, which had been introduced subsequently; if he had used it, the results might have been very different. He personally had never come across any converter steel which would give the same physical results as would electric steel. It might be that some of the later steels produced by Mr. Deschamps were better than electric steel, but he personally had tested steels made by a great number of foundries in this country and his tests had always shown that the well-made basic electric steel was the finest he had ever experienced so far as physical properties were concerned.

How Quality of Tropenas Steel has Improved.

Mr. P. Fassotte, although pleased that Mr. Lake had defended Dr. Vanzetti, said that he personally felt inclined to agree entirely with Mr. Deschamps' onslaught upon the theories developed by Dr. Vanzetti. He was most decidedly of the opinion, on the basis of the cost of current and the price of scrap which Dr. Vanzetti had indicated were ruling in Italy, that with proper converter practice he would make steel more cheaply. The proper course to take

with regard to converter practice was to ignore the text-books, as they were completely out of date. During the last 10 years converter practice had been absolutely revolutionised in two essential respects—the economy of the process and the quality of the metal produced. It was a steel which, in the hands of the steelfounder, offered manifest advantages over any other type, and Mr. Lake must have been right in assuming that the converter steels which he had examined must have been made by the old method. The results which Mr. Deschamps had obtained were indeed exceptional, but they were not exceptional, perhaps, to the extent to which Mr. Lake believed them to be. In quite a number of foundries on the Continent and in this country nowadays, converter steel was being produced, day in and day out, of a quality absolutely undreamed of 10 years ago.

The factor which influenced to the largest extent the economic aspect of converter practice was, of course, the melting loss. With melting losses as high as 20 or 30 per cent., as indicated by Dr. Vanzetti, it was quite conceivable that the process would be expensive, but he could confirm that the results such as had been obtained by Mr. Deschamps, or at any rate results very near to them, were being obtained in other converter installations. The hot tears which Mr. Lake had experienced in the particular type of steel castings he had referred to were due, no doubt, to high sulphur content, because nowadays a hot tear was no more common in a converter foundry than in a foundry using the electric process. He personally had worked in a foundry having both electric furnaces and converters, but he had never experienced the difference to which Mr. Lake had referred. At this foundry, the converter was oil fired; every one of the foremen there, when they had to cast an intricate casting, preferred converter to electric steel. One of the reasons for that had been suggested to him by Mr. C. H. Kain, who had said that when electric steel was bad it was damned bad. That, in a way, confirmed what Dr.

Vanzetti had said. Perhaps the position was best summed up by saying that it was more easy to make good converter steel regularly than to make good electric steel regularly; or, that one needed a really good operator to run a converter, and one needed an exceptionally good operator to operate an electric furnace. The discussion as to the merits of the two steels was really academic; in practice the whole question resolved itself into the quality of the operator.

Finally, he said that in a recent article Mr. Deschamps had expressed hopes about the rotary furnace in connection with steelmaking; nobody shared those hopes more ardently than he.

The Chairman, having seen the operation of the electric-steel furnace in Scandinavia and the converter process in England, said he had gained the impression that more labour was required in connection with the converter process than the electric process, and he asked what was the compensating factor which would enable cheap converter steel, as against electric steel, to be produced. Of course, much depended upon the cost of electricity in the case of the electric furnace.

A Message of Appreciation.

Mr. J. Cameron (Past-President of the Institute) took the opportunity to express to the London Branch the sympathy of himself and the Scottish Branch in the loss of Mr. Dews. He also took the opportunity to pay his personal tribute to the Vanzetti family, and to emphasise the value of the policy of the Institute in fostering valuable international associations. The late Mr. Oliver Stubbs, a President of the Institute, was one of the first British foundrymen to point out the good results which must accrue from these international friendships, and from the consequent interchange of views between foundrymen of various countries. In adopting that policy the foundrymen had set an example to the world, and it had been a great success. Mr. Cameron added that he had had the pleasure of knowing both Dr. Guido Vanzetti

and his worthy father, Mr. Carlo Vanzetti. The International Foundry Congress and Exhibition at Milan in 1931 had been such a success, and Mr. Carlo Vanzetti had taken such a prominent part in connection with it that he had been honoured by his King; but a great deal of the work had been done by Dr. Guido Vanzetti, who had been guide, philosopher and friend to all who had attended. The Italian Congress would never be forgotten, and those who had attended would always recall with pleasure the hospitality extended to them. One important factor affecting the foundry industry in Italy was the lack of deposits of coal, and that, of course, had its influence on the adoption of the electric furnace. He recalled that at the Vanzetti foundry at Milan the production of cast iron was a sideline, and they had specialised in the production of an alloy having a wonderful resistance to corrosion, and which was used to some extent for making artistic ornamental figures for gardens, etc.

Bracketing Eliminates Cracks.

Mr. H. O. Slater supported Mr. Cameron's remarks concerning the policy adopted by British foundrymen in the direction of establishing and maintaining international friendships, and recalled that as far back as 1920-21, when he was President of the London Branch, a lecture was delivered to the Branch by Mr. Ronceray; he believed that this was Mr. Ronceray's first lecture in England. He recalled with pleasure the high quality of the lecture, and he believed that that was the first occasion on which the use of pencil runners in the making of castings had been mentioned in a lecture in this country; and there had been a very valuable discussion. Dr. Vanzetti, in his lecture, had well maintained the standard set by Mr. Ronceray years ago, and was to be congratulated upon it.

Discussing the references made to the merits of converter and electric steel, Mr. Slater expressed agreement with the view that much depends upon the skill of the operators of the

furnaces, and added that much depended also upon the skill of the moulders. In this connection he related an experience concerning the casting of a steel smokebox for a railway engine. This casting was large, but very thin, and a number of cracks had developed in it. At first the steel was blamed, but after certain experiments had been carried out, by bracketing and so on, it was appreciated that the steel was not to blame. The method of making the core iron was altered, wood being incorporated in the place of loose iron rods in building up the cores, so that when the cores were dried the wood burned away to a large extent, the walls of the cores being made as thin as possible, and the interior filled with coke breeze, both wood and breeze made the cores almost collapsible, also greatly facilitating the removal of the main core iron, which was removed as soon as possible after casting. When that was done, and the whole of the brackets dispensed with, the casting was produced perfectly; that was a tribute to the skill of the moulder.

The Author's Reply.

Dr. Vanzetti, replying to the discussion, said that it was very difficult to compare figures obtained by the different processes of steel manufacturing, because there were so many variables entering into the problem. Moreover, that very good converter practice and electric-steel making were rarely found in the same foundry. Commenting on the references made to the importance of the skill of the operator, he said that this too introduced another variable into any comparisons made between converter and electric furnace; he pointed out that Mr. Deschamps was not able to run his electric furnace well enough, and no doubt Mr. Deschamps would insist that the founders at Milan were not able to run their converters satisfactorily.

With regard to melting losses, Dr. Vanzetti remembered that in his foundry the converter was used only in special cases, *i.e.*, for pouring large castings by the system described, which

could not be poured by other processes because of the limited capacity of furnaces. For this reason, he declared, the steel had to be poured very hot from the converter as it had to be kept a few hours in the mixer. No doubt, he continued, other foundries that used the converter more generally had attained better results, but he did not think that many people reached the stage arrived at by Mr. Deschamps in connection with converter practice, by his long experience and skill. The labour costs depend upon the system of operation. At the Milan foundry, in order to produce large castings with two converters of one ton capacity, a special organisation was required, and therefore this method of running was rather expensive. They had tried to compare the costs when using a converter and an electric furnace in their own foundry, and had come to the conclusion that the costs for the actual melting of steel were about the same in each case, in spite of the high cost of electric power in that city. However, they found that unless the number of rejections of converter-steel castings were reduced, the advantage was with the electric steel.

Life Tests.

Replying to Mr. Deschamps, Dr. Vanzetti said that from the purchaser's point of view the mechanical properties of the steel were of course more important than the chemical ones, but that from a general point of view the chemical are no less important than the mechanical, as the latter may be said to depend on the former. As to the causes of tears and cracks in steel castings produced with the converter, Dr. Vanzetti did not think that these were due only to the sulphur content; figures had been given which showed that in an American foundry cracks and tears had developed in castings made from converter steel in which the sulphur content was less than that of electric steel from which castings free from cracks had been obtained.

Discussing the question of life, Dr. Vanzetti stated that one ought to compare the acid

converter to the acid-electric furnace and not to the basic one, because the steel obtained from a basic furnace was not so fluid. He did not think it was altogether only a matter of temperature of pouring, as it seemed that there was in the acid steel a more rapid rising of the occlusions from the bath to the surface. But, he asked, was this increase in rising velocity the cause or perhaps only a consequence of the lower viscosity? It has also been asserted, according to the speaker, that the good life of acid steel was due to the fact that silicon *in statu nascendi* is more active and gives a better deoxydation.

Finally, Dr. Vanzetti expressed thanks to Mr. Cameron for his very kind words about the congress of Milan, and said that Italians had tried to accord to the English the same kind reception that they themselves had been given every time they visited England.

Vote of Thanks.

Mr. A. W. G. Bagshawe (Vice-President of the Branch), proposing a vote of thanks to Dr. Vanzetti, said the Paper was a very human one, and was of great interest to any ironfounder. He also congratulated Dr. Vanzetti upon having established throughout the Paper a reasonable balance between theory and practice, because that was something which we had been aspiring to for years, and Dr. Vanzetti had given a very good lead in that direction. He hoped that Dr. Vanzetti had gained information from the discussion in return for the information that he had given in the Paper, and looked forward to further opportunities of hearing lectures by Dr. Vanzetti in the future.

Mr. Deschamps seconded, and also expressed the hope that there would be further opportunities of meeting Dr. Vanzetti in the future.

The vote of thanks was carried with acclamation.

Dr. Vanzetti, responding, again expressed thanks for the reception accorded him, and assured the members that he had learned much that was of interest. Although it was of great

value for him to be able to visit many foundries all over Europe and in America, and to hear the views of other foundrymen, he had actually only been working in the foundry for two years. It was because of his short practical experience that he had been rather diffident about accepting an invitation to deliver a lecture before masters of the art of founding.

The Discussion by the Lancashire Branch.

The Chairman (Mr. Roy Stubbs) said this visit of Dr. Vanzetti's would go far to extend the activities of the Institute by co-operation with the Italian foundrymen. It was surprising that the Italian nation had worked itself up to the second place in the world's production of electric steel castings, particularly when one considered that all their pig and coal was imported from abroad. If they had those raw materials in their own country, they would make much greater progress.

Vote of Thanks.

Mr. E. Flower said the Lancashire Branch were honoured by the presence of Dr. Vanzetti, and he regretted that the approach of the first holiday of 1932 had lessened the attendance. He was surprised at the amount of time that Dr. Vanzetti gave to the advantages of the electric furnace compared with any other furnace. He then proposed that a hearty vote of thanks be accorded to Dr. Vanzetti for his lecture. Mr. J. Taylor seconded, and it was carried by acclamation.

Dr. Vanzetti said he came from a family of foundrymen, but it should be understood that it was only two years ago since he started with plant operation. He thanked the members for the kind reception they had given him, and he hoped to see them in Italy some time.

Life of Hearths.

Mr. E. Flower asked whether Dr. Vanzetti had any trouble with the refractory linings of

the electric furnace. From conversations, he gathered that was a major trouble, as manufacturers were unable to find a refractory that would withstand the intense heat required for this class of furnace.

Dr. Vanzetti replied that they had used basic furnaces for many years, and were now experimenting with acid ones. They used magnesite bricks for the walls and silica bricks for the roof. They were now testing the efficiency of chromite for door jambs, but the results were not yet available. They did not have any trouble with actual lining, although some of their furnaces had conductive hearths.

Tundish Practice.

Mr. J. T. Parsons asked for further information on the subject of tundishes, and the steps they took when they met with a running stopper?

Dr. Vanzetti said that the use of an ordinary bottom-pouring ladle, if of 3 tons capacity, was liable to disturb the sand of the mould being cast and result in dirty steel. Therefore, to break the force of the stream they used a tundish.

Mr. Parsons explained that he once adopted the practice of filling hand shanks from a crane-suspended bottom-pouring ladle, but had discarded it, as he encountered trouble from running stoppers.

Dr. Vanzetti: In which way?

Mr. Parsons: The existence of a running stopper that could not be shut off.

Dr. Vanzetti said he used a graphite stopper and a fireclay nozzle.

Mr. Parsons asked whether such a thing as a running stopper was unknown in Milan.

Dr. Vanzetti said it happened very occasionally, but the German stoppers used were very good, and we rarely have any trouble with them, the exceptions being manganese steel. He often opened the stopper 180 times without any trouble when using a 3-ton ladle.

Mr. Parsons said they had great trouble with one furnace, and they had to shut it down three times within probably four months, yet they had had a second one running three years, which made 1,200 heats weighing 70 cwts. each.

Dr. Vanzetti said a furnace lasted about five months, working about six heats per day, equivalent to about 1,000 heats. It was about three tons every heat; so it was about 3,000 tons.

He also said if anyone present was using a converter he would be interested to know about the melting loss.

Melting Losses.

Mr. Masters said there were many points in connection with converters and melting loss. He recently had the pleasure of going through one of the largest converter plants in the country on a special job and he inquired what the melting loss was. It was given to him as 18 per cent. In one part of his Paper Dr. Vanzetti mentioned the desulphurising of metal and the rapid destruction of the linings of ladles used. What particular process of desulphurising did Dr. Vanzetti use?

Dr. Vanzetti said he used no process at all as the scrap available was low in sulphur, he had, however, referred to two processes—the Stoughton and the Scharlibbe.

Mr. Masters said the particular method he claimed to be conversant with was desulphurising in the ladle. One could claim to take 50 per cent. of the sulphur content out—that is, if the sulphur content exceeded 0.6 per cent.—for the purpose of casting into ingots for rail-making and the like. If the sulphur exceeded 0.06 per cent. it would not pass specification. In this particular process the metal was brought direct from the blast furnace in 20-ton lots and put into a producer gas-fired receiver or mixer which contained about 160 tons. It was rocked just to induce a modicum of mixing and also to absorb a certain amount of the radiation from the lining of the receiver by the metal. Unless a special lining was used for the ladle

which conveyed the metal from the blast furnace to the mixer rapid erosion of the lining resulted and the desulphurising reagent did not act at all. Instead of having a sulphur reduction of 50 per cent. of the original content, it only gave about 10 per cent. or perhaps 15 at a maximum. By using a special neutral lining it resulted in a full 50 per cent. desulphurisation.

A Facing Development.

For the casting of green-sand moulds the addition of 1 per cent. of dextrine was said to be beneficial. He presumed it would give a good skin on the casting. That particular method had been developed the last four years, more so than it had ever been in this country before. Castings which up to four years ago were cast in dry-sand moulds were now being made much more economically. Castings were produced having a much better skin, and were apparently superior both physically and in general appearance than they were when made in the ordinary compo moulds. These moulds were made from a silica sand and a certain amount of binders which kept the mould rigid and seemed to protect its surface from erosion, yielding excellent stripping conditions. Some of the castings he had seen, which weighed as much as 4 tons, gave the impression that they had been made in grey iron. Finally he asked the nature of the sand used. Was it pure silica or argillaceous?

Dr. Vanzetti said that in Italy good sands were available for iron moulding but not for steel, due to their low fusibility. Normally French sands were used, such as the yellow sand from Coincy and the red sand of St. Hilaire. Their facing sand was prepared by mixing 70 to 75 per cent. of yellow sand and about 25 per cent. of old sand with about $3\frac{1}{2}$ per cent. of water. The yellow sand they used contained about 90 per cent. of silica and about 10 per cent. of clay. What kind of testing apparatus did Mr. Masters use? Did he use the American Foundrymen's Association machines?

Mr. Masters said he used the British Cast Iron Research Association apparatus, and asked whether it was customary to dry the sand before mixing.

Dr. Vanzetti replied that as new sands obviously possessed a varying moisture content they preferred to dry it in order to institute standard conditions. In stainless-steel castings Bentonite was used, but as it absorbed moisture the moulds must not be left standing, as this binder was apt to absorb moisture.

Sand Preparation.

Mr. E. Longden said Dr. Vanzetti conveyed the impression that he laid very great stress on the type of furnace because of the difficulties of fuel supply. That was a question of economics, and the qualities of steel appeared to be more or less a secondary consideration in regard to the question of cost. The controversy raging round the qualities of steel would continue. They did not appear to have any real proof as to the values of the different methods of melting the steel.

The loss of steel during converting would mainly depend upon the process and class of metal used. In certain districts melting with the cupola and tropenas converter—duplexing—they were melting probably 75 per cent. steel, so that there would be the loss in the cupola prior to converting and they would also have a loss during converting. He would say that in England an average of 10 per cent. loss would be the case in practice. That was allowing for the loss of the elements in cupola and converter. He thought that was really the true situation. The 10 per cent. which was mentioned to Dr. Vanzetti in London did represent the average loss, he thought. Would Dr. Vanzetti enlarge a little on the value of sand in steel practice? In England, in up-to-date steel foundries, they attempted to clean the sand of silt. That was very important in steel foundry sands.

Dr. Vanzetti said they had in practice two systems. They used a dry process and also

another system which was called washing the sand. They had used it for some time and were still using it. Some people used a suction system. His foundry had tried it and had had very good results. They used it especially for the sand coming out from the cleaning department; therefore it was yielding virtually a pure silica sand in the washing plant. They removed the burnt part and the recovered washed sand was utilised especially for cores. The sand was mixed with water and there was a sort of rake or scraper which pushed it up little by little along the inclined washing table, and the silt remained in the water and was separated from the good sand. The recovered sand was taken out from the top of the table. The whole of the water was pumped out into a large storage tank, where the clay and silt were allowed to settle out. This by-product was used in the foundry for secondary purposes.

Mr. E. Longden: It is the flotation process.

Mr. Vanzetti: Yes.

Mr. Longden said they were often asked to install various types of furnaces for melting grey iron. He did not suppose there were more than two or three electric furnaces in Great Britain melting grey iron. He believed in Italy a large number of furnaces were melting grey iron. It was a question of fuel costs mainly.

Dr. Vanzetti said that in his foundry for the last three years high-tensile irons were being made giving normally between 18 and 25 tons per sq. in.

Scottish Branch.*

HIGH-STRENGTH SAND-CASTING ALUMINIUM ALLOYS.

By W. C. Devereux.

The subject will be confined to those alloys now used extensively for highly-stressed or special parts, such as " Y " alloy the R.R. alloys, and the 4 per cent. copper alloys used widely in America. At no time in the history of non-ferrous alloys has any one alloy progressed and been used so extensively in such a short time from its first appearance as has the R.R. range. It must be borne in mind, however, that these alloys were, in their experimental days, subject to investigation and research by a firm which has a world-wide reputation for the thoroughness with which it conducts its investigation before being satisfied and incorporating a change in its products. The R.R. alloys were not marketed for years after the first conception, and have been subjected to every form of test for the application they are essentially designed for, namely, aircraft construction, and no greater test could be put to any material.

The British are fortunate in having in this country designers—particularly in the aircraft industry—who are not content merely to judge a cast material on its separately-cast test-piece values. It is recognised generally that a material which is rigid, high in creep resistance, and has good casting qualities, ensuring castings free from local cracks, porosity and draws, and not subject to weakness due to hot-shortness or shrinkage, is much to be preferred to one having better physical properties in the test-bar but subject in some degree to the defects enumerated; in other words, it is useless making a casting

* Also presented to Sheffield Branch and Burnley Section of Lancashire Branch.

with good test-bar results if the casting itself has a local weakness.

Competition from Drop Forgings.

The use of a chill-cast test-piece as used in England in aluminium castings is a very good comparative test of the consistent quality of a material, although being no measure even in physical properties as to the superiority of one alloy over another, insomuch that one alloy may need perhaps an entirely different method of feeding from another; therefore the test is only comparative for the actual alloy under test. The chill-cast test-bar, and indeed the separately-cast bar serves a useful purpose, but it is felt that its use has been responsible for an attitude in some foundries of aiming for good test results to the neglect of the actual casting, and that development has been along the lines of obtaining good test-pieces to the detriment generally of developing the best method of casting. The inconsistency of the castings as a result of this policy is one of the important factors which has led to the supplanting of castings in many cases by forgings, especially with aluminium alloys. The enormous improvement in modern machine tools, combined with the ease with which aluminium alloys are machined, not to mention the ingenuity of the production engineer, has assisted the competition of forging with casting. It is not so much because the casting, made correctly and consistently, would not satisfy the demand of the designers—they very often would —but in the aircraft industry so much difficulty has been experienced in obtaining such castings that to ensure continuity of production firms have been forced into the use of forgings where they would never have gone to the development for other reasons. Having taken this step they find that however difficult the shape of the part, the manufacture is not so formidable, made as a forging, as was supposed, and they have the assurance that practically every forging entering into the receiving department can be counted on as producing a finished part.

Casting Properties and Elimination of Chills.

It is vital, therefore, that in deciding on materials a founder should decide on those that respond well in the foundry, and should study most closely the correct method of casting to obtain consistent qualities throughout the casting. The more the elimination of chills can be brought about in the casting of aluminium alloys, the sooner will this be obtained.

Most founders are familiar with the specification of analysis of the various materials under discussion, but for completion they have been set out in Tables I and II. Letters patent have been issued covering the R.R. range of alloys, their manufacture and heat-treatment, the numbers being 281,912, 292,407, 300,078, 312,555, etc.

TABLE I.—*Percentage Composition of Casting Alloys (Remainder Aluminium).*

Alloy.	Cu.	Ni.	Mg.	Ti.	Fe.	Si.
R.R. 50 ..	1.2	1.3	0.1	0.18	1.1	2.2
R.R. 53 ..	2.2	1.3	1.6	0.08	1.4	1.2
"Y" alloy	4.0	2.0	1.5	—	0.3	0.3
American alloy ..	4.0	—	—	—	0.6	0.8

Mechanical Properties of Light Alloys.

Table I shows the chemical analysis of the alloys, whilst Fig. 1 gives stress-strain diagrams, the sand-cast test-bars being cast to shape, the parallel portion 0.60 in. dia. machined to 0.564 in. dia. The tests are taken in the condition in which the material is recommended for use, and Table II gives the heat-treatment to which the alloy has been subjected.

Fatigue tests have been conducted on an Amsler-Wohler type machine, and Fig. 2 gives the curves, including those of some of the older alloys. The test-pieces are sand cast 1 in. dia. by 9 in. long, turned to 0.53 in. dia. at the maximum bending moment.

TABLE II.—*Heat-Treatment of Casting Alloys.*

Alloy.	Solution treatment.			Precipitation treatment.		
	Temperature.	Time.	Quench.	Temperature.	Time.	Quench.
	Deg. C.	Hrs.		Deg. C.	Hrs.	
R.R. 50	—	—	—	170	20	Cold water.
R.R. 53	530	2	Cold water	170	20	Cold water.
"Y" alloy	520	2	Boiling water	5 days' natural ageing at air temperature.		
American alloy	520	12	,,	160	20	Water.

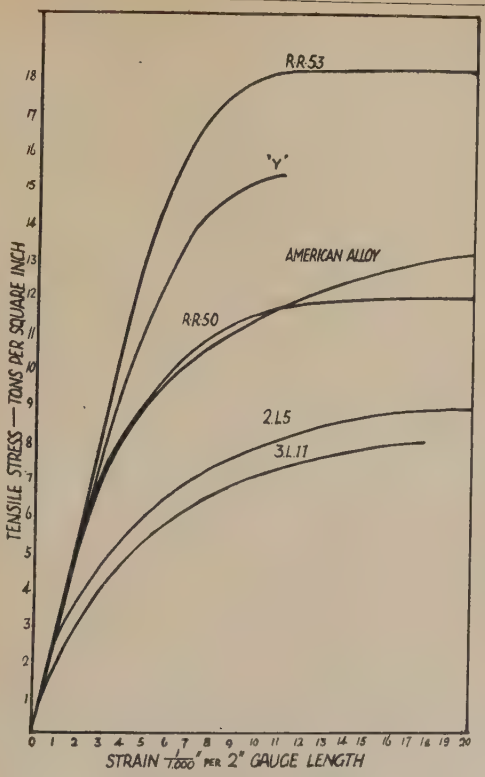


FIG. 1.—STRESS-STRAIN DIAGRAMS FOR SAND-CAST ALLOYS.

Alloy.	Limit of proportionality.	0.1 per cent proof stress.	Y.P.	Ultimate stress.	Brinell.	Elongation on 2 in., per cent
R.R.50, heat-treated ..	6.5	10.0	11.0	12.8	76	3
R.R.53, heat-treated ..	14.0	17.5	—	18.4	134	1
American alloy, heat-treated ..	6.0	9.5	12.0	13.6	85	2
"Y" alloy, heat-treated ..	7.5	14.0	—	15.5	121	0.5
2L5 ..	2.5	5.6	7.5	10.6	75	2.5
3L11 ..	2.0	3.8	—	8.8	50	1

All stresses in tons per sq. in.

An interesting test has been made on the machine shown in Fig. 3 (page 528), which may be designated deflection fatigue; the machine is run slowly at 42 reversals per min., the test-piece being sand cast near to shape and machined all over. The figures obtained are shown in Table III.

What is illuminating in this test is the influence of work hardening on the high-copper alloys, as demonstrated by the increase of the elastic limit denoted by the larger number of

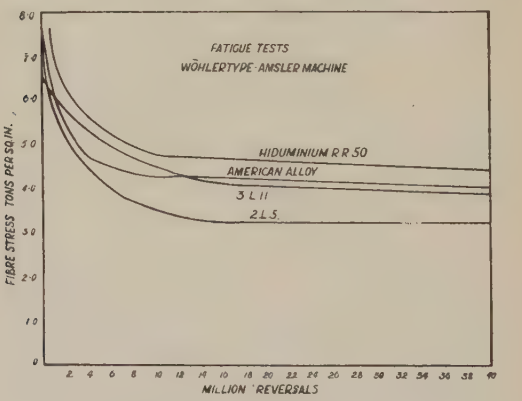


FIG. 2.—FATIGUE-TEST CURVES OF SAND-CAST ALLOYS.

reversals at the small deflection; this work hardening not having time to occur at the higher deflections, where immediately the elastic limit is exceeded. Likewise this test shows the advantage of a material having the higher elastic limit and the ability to resist work hardening, as do the R.R. alloys. In this connection it is interesting to compare the statement of Ludwick before the New International Association for Testing Materials at Zürich in September, 1931. He states: "The resistance to alternating stress showed itself to be dependent chiefly on the resistance to deformation and to

TABLE III.—*Deflection Fatigue Results on Sand-Cast Alloys.*

Deflection.		R.R. 50.	R.R. 53.	"Y" alloy.	2L5.	3L11.	195.	195.
Distance from vertical.	Total angle.	H.T.	H.T.	H.T.	As-cast.	As-cast.	4 hrs. at 520° C.	12 hrs. 520° C. 20 hrs. 170° C.
$\frac{1}{16}$ in.	2° 20″	39,270	102,354	113,492	45,598	60,768	57,826	118,764
$\frac{3}{32}$ in.	3° 30″	6,312	16,766	10,540	5,678	2,028	7,328	15,446
$\frac{1}{8}$ in.	4° 40″	766	1,670	920	428	300	364	1,514

BREAKING POINT
2.5"
9"
12"
8½"
TEST PIECE FOR WHIRLING R.R.

cleavage, but not to the ability to undergo deformation."

Tests were conducted on a machine shown in Fig. 4. The test is rather a good comparative fatigue test of actual sand-cast specimens. The sketch in the corner of the figure gives the actual size of the test-pieces. Tests are taken on six castings of each material, the average figures being given in Table IV. The machine is rotated at 1,420 r.p.m. and is run with a load of 200 lbs. for 10 hrs., the load then being increased every 2 hrs. by 20 lbs., until fracture occurs. The alloys of "Y" alloy and R.R. 53 are largely

TABLE IV.—*Whirling Rig Test Results.*

Material.	Average ultimate load, lbs.	Total hours run.	Brinell hardness of specimens.	Condition.
R.R. 50 ..	590	48¾	80	Heat-treated.
2L5 ..	545	43	87	As-cast.
3L11 ..	480	36½	67	As-cast.
"Y" alloy	490	38	104	Heat-treated.
American alloy ..	480	37	80	Heat-treated.

used in the chill-cast state, possibly the most use being made of these two alloys in the form of pistons. The physical properties of these alloys are therefore given in the chill-cast state. The influence of the type of chill is very noticeable, as will be seen when considering the two types of chill moulds shown in Fig. 5, and for purposes of comparison the tests shown in Table V have been included.

Solidification Range and Soundness.

It is remarkable that those alloys having a prolonged solidification range respond better in the plain type of mould, as compared to the mould with heavy feeders, than the alloys having a more eutectic composition. This is probably the reason why, in casting R.R. 50, one needs

TABLE V.

Alloy.	Type of mould.	0.1 per cent. proof stress. Tons per sq. in.	Ultimate stress. Tons per sq. in.	Elongation. Per cent. on 2 in.	Brinell hardness.
R.R. 50, heat-treated	B.E.S.A. type	8.0	13.6	4.5	80
	R.R. type with feeder head	10.0	16.2	6.5	83
R.R. 53, heat-treated	B.E.S.A. type	19.8	22.0	1.0	140
	R.R. type with feeder head	23.0	25.3	2.5	148
"Y" alloy, heat-treated	B.E.S.A. type	12.5	20.0	3.0	110
	R.R. type with feeder head	12.4	19.0	2.5	114

to use larger runners, risers and shrinkage pads, dispensing with the use of chills to a large extent. Note, for instance, the improvement with feeding of the 2L5 and R.R. 50 alloy, and compare this with " Y " alloy; then compare

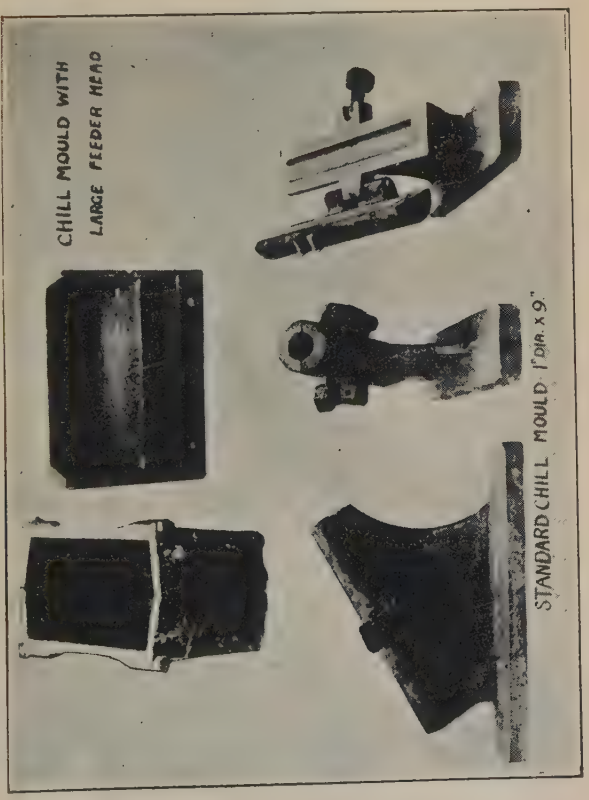


FIG. 5.—STANDARD CHILL MOULDS FOR TEST-PIECES.

the melting curves of these two alloys in Fig. 13 with " Y " alloy in Fig. 14.

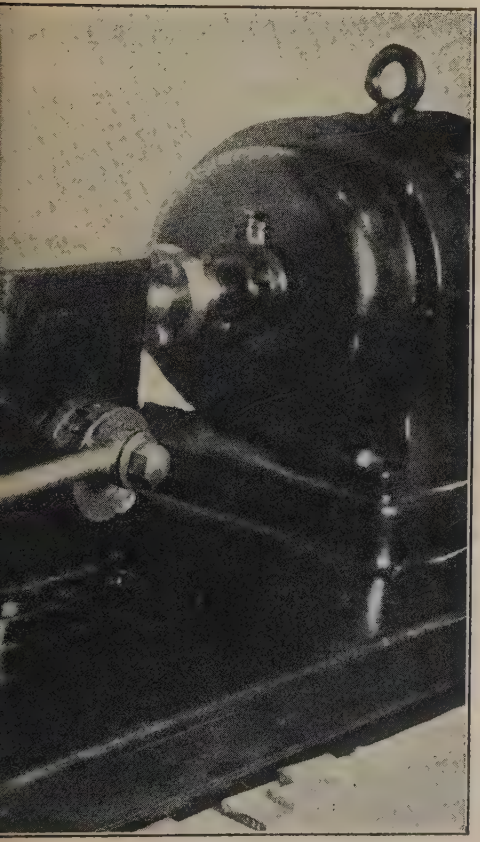
Another interesting point is the effect of the mould on the 0.1 per cent. proof stress, and the comparison of these figures with the proof stress

of the sand-cast test-piece. Undoubtedly the reason for the seeming anomaly between the proof stress in the straight mould without feeder,

FIG. 3.—A MACHINE DESIGNED

and the sand-cast test-piece in the R.R. 50 alloy, is explained that the solidification of the material is more rapid, and the material in the

B.E.S.A. mould is not fed as it should be, and as it would be in any die-cast application or in the other mould. Obviously then, the core has a



TAINING "DEFLECTION FATIGUE."

certain weakness, which would result in a lowered proof-stress value. The ultimate stress would be assisted by the good chilling of the outside

portion of the test-piece. The reason for the necessity of feeding to obtain the best results can be seen. The fatigue curves of "Y" and R.R. 53 in the chill-cast state are given in Fig. 6 as compared with L. 8 chill-cast, the test-piece being cast in 1-in. dia. chills and heat-treated. The curves of "Y" alloy and R.R. 53 are seen to cross at about 7.5 tons per sq. in. This is due to the higher 0.1 per cent. proof stress of R.R. 53 allowing a greater number of reversals at the heavier stresses, thus showing R.R. 53 to be the more suitable material where periodic severe

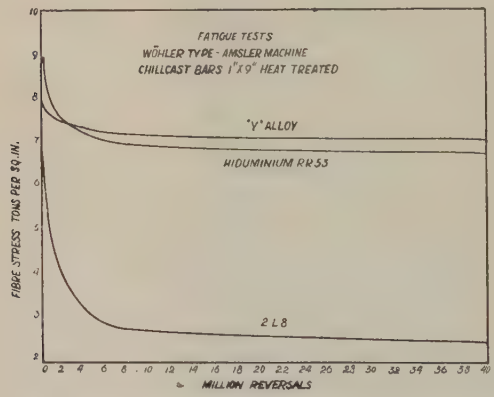


FIG. 6.—FATIGUE-TEST CURVES OF CHILL-CAST ALLOYS.

overloading is at all likely to occur. As the "Y" alloy and R.R. 53 are used mostly for pistons and sand-cast cylinder-heads, or for parts subject to work at elevated temperatures, the chart, Fig. 7, giving the effect of temperature on the tensile strength, may be interesting, whilst chart Fig. 8 gives the effect of temperature on the Brinell hardness. The tests have been taken on 1-in. dia. chill-cast test-bars, cast in accordance with the B.E.S.A. specification, and the tests taken at the various temperatures after holding the test-piece at the temperature for 30 min. Fig. 9 shows a

sketch of the furnace used, the Brinell-hardness figure being taken by holding the test-piece at temperature in a bath of oil heated and held at temperature for 30 min., the test being taken at the temperature.

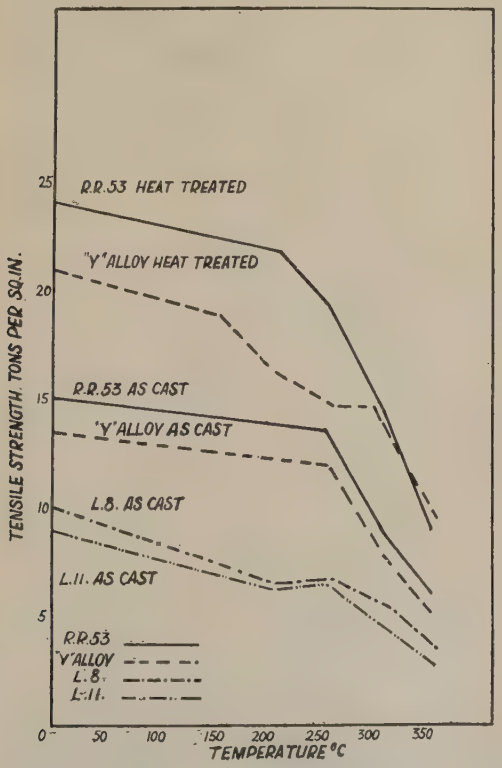


FIG. 7.—EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF VARIOUS ALUMINIUM ALLOYS.

Wear and Friction Properties.

Before proceeding to the actual casting qualities of the materials, it is proposed to complete

what one may call physical tests with rather an unusual test on a machine installed in the Rolls-Royce laboratory. It is an attempt to measure the wear and friction properties of the material to be used for pistons. The machine is shown in Fig. 10. The four test-pieces are held in a chuck, shown on the table. This is rotated through a swivel joint from the spindle directly

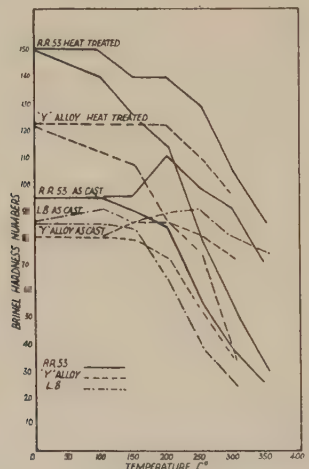


FIG. 8.—EFFECT OF TEMPERATURE ON THE BRINELL HARDNESS OF VARIOUS ALUMINIUM ALLOYS, WITH RECOVERY VALUES.

connected to the motor. The discs run in a bath of P. 4 oil against a steel disc of 0.5 per cent. carbon steel (B.E.S.A. S. 70). The oil is heated over the range up to 200 deg. C. The disc is loaded to 100 lbs. per sq. in. and runs at 545 r.p.m. Amperes give the measure of relative friction. Fig. 11 is a chart of the results of this test on various materials, whilst Table VI gives other essential characteristics.

Casting Properties.

The casting qualities most desirable are low contraction and hot-strength to withstand the stress of contraction on to the cores. The material must be fluid in the mould, and have little skin friction. Invariably, good casting alloys show a large tendency to pipe at the risers, that is, that the smaller the distance of the liquidus from the solidus point, the more the necessity of providing large runners and risers, as from the commencement of crystallisation, a shorter time will there be for the metal to feed

TABLE VI.

Alloy.	Specific gravity.	Thermal conductivity. C.G.S. units at 18 deg.C.	Coefficient of linear expansion.		
			20–100 deg. C.	20–200 deg. C.	20–300 deg. C.
R.R. 50 ..	2.73	0.415	22.0	23.1	24.1
R.R. 53 ..	2.73	0.43	22.2	23.3	23.8
"Y" alloy	2.78	0.42	22.0	24.0	25.6
2L5 ..	3.0	0.30	25.5	27.2	28.2
2L8 ..	2.88	0.34	22.4	23.6	28.6
3L11 ..	2.88	0.387	24.6	26.2	28.0
American alloy ..	2.79	0.40	23.2	24.6	26.7

before complete solidification, but this is a very desirable feature in providing castings sound, free from porous places, shrinkage cracks and draws, and to the elimination of that curse to consistent results, the use of chills.

To give some comparison of the qualities of various alloys, judged from the standpoint of good casting qualities, Table VII gives the linear contraction of the alloys under discussion, whilst the hot-strength in the mould was tested by placing a tee-shaped pattern in a sand mould allowing contraction on to two steel distance-pieces, as shown in Fig. 12. The test was commenced with the distance-pieces fitting the pattern, and subsequent tests done by machining clearances between the distance-pieces and the

pattern, until all materials remained unbroken —of course, the clearance was filled in with sand. Table VIII gives the result of this test.

R.R. 53 special is used by the author in the manufacture of exceptionally delicate die castings, such parts as die-cast radial cylinder-heads, etc. The silicon content is brought up to 2 per cent., some sacrifice being made in the ultimate strength and strength at temperature to secure exceptionally good die-casting properties, but the standard R.R. 53 is used for all pistons and other castings, except those that are extremely delicate. The added silicon reduces the ultimate strength after heat-treatment by 2 to 2.5 tons, but the difference is not so much when at the higher temperatures. Fig. 14A shows a number

TABLE VII.—*Linear Casting Contraction.*

Alloy.	In. per ft.	Pattern-makers' scale.	Contraction per cent.
"Y" alloy ..	0.155	1/77	1.29
R.R. 50 ..	0.125	1/96	1.042
R.R. 53 ..	0.140	1/86	1.163
American alloy	0.188	1/64	1.563
2L5	0.154	1/78	1.266
3L11	0.128	1/83	1.205

of dilation curves, the characteristic hump in the R.R. 50 curve at the temperature below precipitation low-temperature heat-treatment being outstanding. The heat-treatment desirable for the alloys under discussion has been given in Table II. The great drawback with those alloys needing the high-temperature solution treatment is the difficulty in preventing distortion, cracking and heat-strain set up when dealing with large castings. Probably there is no advantage to be gained by giving a high-temperature treatment to sand-cast alloys. Generally speaking, a sand casting is in a strained condition, as it is stressed in cooling by the resistance of the cores; this strain very often is accentuated by the high-temperature treatment and the subsequent quench. With delicate castings, having

TABLE VIII.—*Hot-Shortness Test.*

Clearance.	Materials.							
	R.R. 50.	DTD. 25.	R.R. 53E. Special.	3L11.	R.R. 53.	"Y" alloy.	2L5.	4 per cent. Cu American alloy.
Nil ..	Unbroken	Unbroken	Unbroken	Broken	Broken	Broken	Broken	Broken
$\frac{2}{64}$ ..	,,	,,	,,	Unbroken	,,	,,	,,	,,
$\frac{3}{64}$ ..	,,	,,	,,	,,	Unbroken	Unbroken	Unbroken	Unbroken

abrupt or distinct changes of section, it is necessary to bring up the temperature very gradually and adequately to support the castings in the furnace and during the quenching operation. If using an electric furnace, it should be done in steps to allow of even distribution of the heat in thin or thick sections. All the well-known

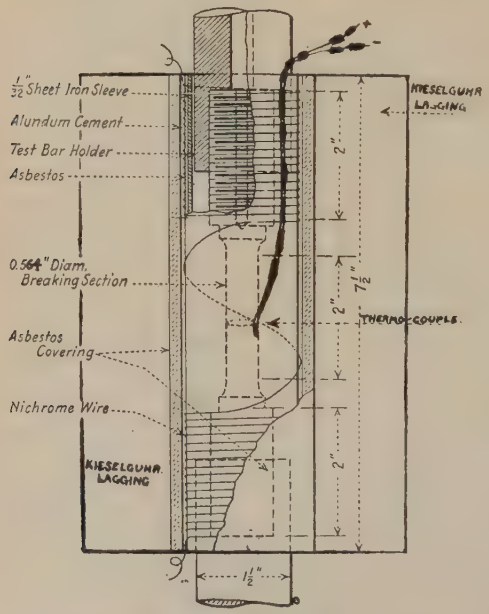


FIG. 9.—HEATING ARRANGEMENT FOR THE ASCERTAINING OF TENSILE PROPERTIES OF ALLOYS AT ELEVATED TEMPERATURES.

electric furnace makers will fit an automatic control which will allow of this bringing up in steps, and when the required temperature is reached, will maintain automatically at this temperature. It has been found that the best method is to employ a salt bath, using frozen crushed salt surrounding the work to commence

FIG. 10.—A MACHINE DESIGNED FOR TESTING THE WEAR AND FRICTION PROPERTIES OF ALLOYS.

with. In design, to obtain the maximum of service demands an accurate knowledge of the characteristics of the alloy, and how best to employ them.

Achieving Lightness of Section.

The present demand is for lightness. The author is convinced that generally the design of aluminium castings is heavier for their service than need be. In the case of aircraft cast-

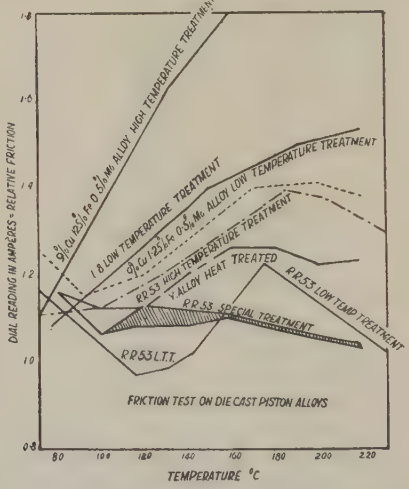


FIG. 11.—FRICTION-TEST CURVES OF DIE-CAST PISTON ALLOYS.

ings, where lightness must be allied with strength, it is noticeable that those firms having their own foundries have been able to reduce the thickness and weight of castings due principally to the fact that they have been able to see exactly the foundry trouble. Some of them use distinct methods of casting, not only to produce castings of good appearance, but regulating the method of casting, gating, etc., to obtain the correct strength in the right place, whereas

it has proved more difficult with the detached foundry which is concerned more in making a good-looking casting that will machine clean.

FIG. 12.—SHOWING THE METHOD USED FOR MAKING HOT-SHORTNESS TEST.

Further, the detached foundry, by using the argument of hold-up in production, has been able to influence the design in the way of increasing thickness, radii and other alterations, many of them made at the sacrifice of lightness. What is inferred is, that there has been more co-operation between the foundryman and the designer when both are working for the same organisation than when the work is going out to the detached foundries. The attitude of many of the smaller detached foundries has not been conducive to the co-operation that is so essential if the casting industry is to be benefited. There

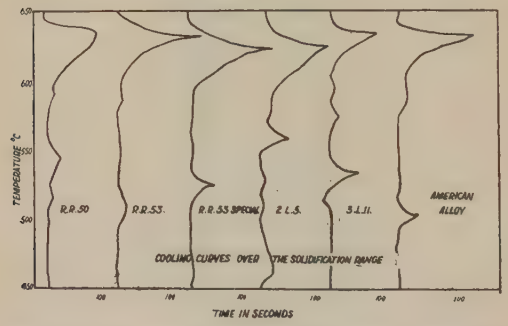


FIG. 13.—COOLING CURVES OF SOME ALUMINIUM ALLOYS OVER THE SOLIDIFICATION RANGE.

is a distinct trend in aircraft design to move away from castings to the more reliable forging, and the companies manufacturing forgings and stampings are showing more willingness to work with the designer.

Of course, there are outstanding instances of foundries that are doing everything possible to give the designer what he wants, but it is feared that even these large companies have been willing to sacrifice much in the general endeavour to meet the extensive demands in castings for lower prices.

It is probably agreed that the general low scale of prices is in a great measure the fault of the

foundry. Obviously, the very low prices now quoted for general and automobile castings can only be obtained by the very large use of secondary or scrap material. Foundries have not exhibited sufficient strength of mind in meeting the demand of the designer and the buyer, and, as is usually the case, any ill-effect will be borne by the foundry eventually.

This apparent transgression from the subject has been made in order, if possible, to stress the

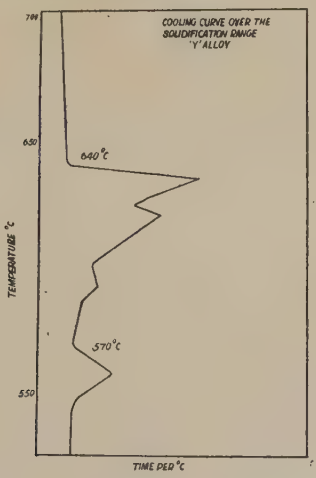


FIG. 14.—COOLING CURVE OF "Y" ALLOY OVER THE SOLIDIFICATION RANGE.

importance of every assistance being given to the designer from the foundry. When this is done efficiently, and sufficiently strongly, it is surprising what good results can be obtained.

Temperature Control.

Temperature control of the melting and pouring is as important as the correct disposition of the runners and risers. The metal for the 4 to 5 per cent. Cu alloy and particularly for

"Y" alloy, should not be allowed to exceed 750 deg. C. in the furnace; with the R.R. 50 alloy it is safe to go up to as high as 820 deg. C., but, of course, this high temperature is never necessary. The pouring temperatures must be accurately controlled, and always the same for each casting; temperatures from 690 deg. C. for heavy work, to 740 deg. C. for thin parts, being the limits in the case of "Y" alloy, but occa-

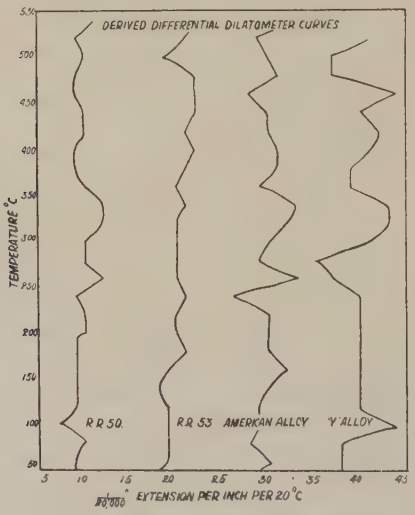


FIG. 14A.—DERIVED DIFFERENTIAL DILATOMETER CURVES OF SOME ALUMINIUM ALLOYS.

sionally one might find that one could cast much thinner parts in the case of R.R. 50 alloy and go up to 770 deg. C., remembering that low temperature decreases contraction during solidification. Stewing of the metal at all costs should be avoided, the mould always being made ready for the metal. In the case where several pots are required to pour a large casting, the practice of using an ingot of material to hold back

a pot of metal is unsatisfactory; a better method, and one used personally, is to use a square of Ni-Cr steel—about 14 lbs.—screwed in the end of a steel rod; it is a much more satisfactory method, and several pots can be controlled to a few degrees. A good method of pyrometer control is to have the indicators enclosed in boxes on posts distributed about the foundry, with

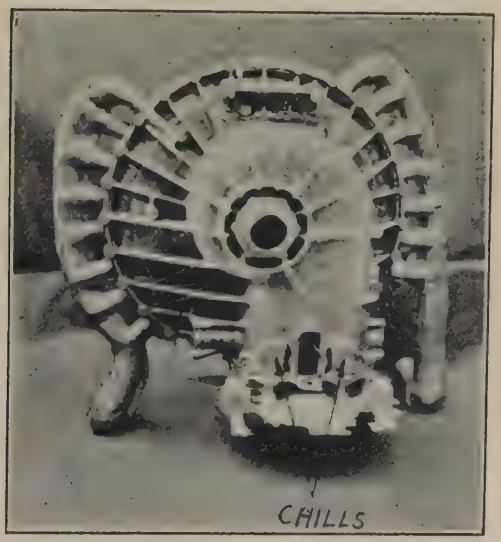


FIG. 15.—A SUPERCHARGER CASTING FOR WHICH ONLY SIX CHILLS ARE USED.

two thermo-couples attached, and a throw-over switch so that one is a check on the other, and one man only reads, probably 20 yds. from the mould, he advising the actual man pouring when the temperature is correct. The detail points in these metals, as in all foundry work, are the ones that make or mar success. It is a good thing to provide a special furnace for heating

pouring pots to receive the metal, and not relying on placing the pots on the melting furnace to warm them.

Practical Details.

In the use of the metal, the Ti-addition in the R.R. 59 certainly acts as a deoxidiser and

Fig. 16.—The Top Face of the Casting shown in Fig. 15.

cleanser, and it is safe to use good heavy scrap, and runners and risers up to 60 per cent. or even more; but in the case of "Y" alloy extreme care must be taken in the case of ingot and scrap to ensure gas-free metal; it is unsafe to use more than 20 per cent. of works scrap and then only the cleanest of material if good results are to be

obtained. The sprues should be kept full during pouring and the metal handled as quietly as possible, pouring in an unbroken stream from a low height. As to sand, any of the usual moulding sands, similar to Red Mansfield, are suitable, and should be used with very little new sand, a small quantity being added occasionally to open the sand a little.

All moulds may be green or skin-dried for heavier work. The same sand is used for core

Fig. 17.—This Supercharger Casting is Made without the Use of Chills.

work, and it is the author's practice to add a little sea sand to the floor sand, about one bucketful of sea sand to three barrow loads of floor sand. Of course, cores are stove-dried. In the case of delicate cores, the author uses 30 parts of sea sand to one of linseed oil base binder.

T

The use of vents and wax tapers should be very carefully studied to see that vents definitely join up and lead out of the mould. The principle may be adopted that, however much one vents,

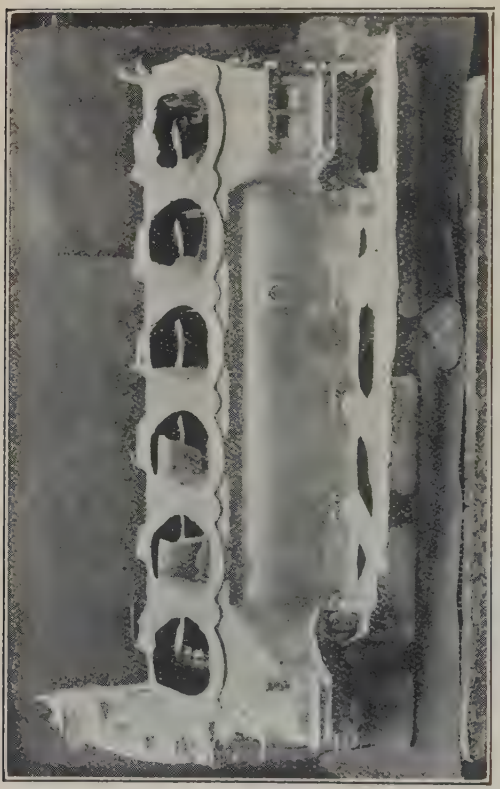


Fig. 18.—A Crankcase Casting also Made without Chills.

one cannot vent too much, but it is useless venting if the vent is at any point trapped and does not lead out of the mould.

As an illustration of the importance of venting, there is illustrated a set of water-jacket cores of

the Rolls-Royce cylinder-block. In addition to wired vents, they use $1\frac{1}{4}$ lbs. of wax taper per set. In the case of " Y " alloy and the 4 to 5 per cent. Cu alloy, runners and risers follow much the usual practice, care, however, being taken to create as little disturbance as possible, the smaller the runner the better. Chills must be adopted at the thick sections to even the solidification of the whole. With the American alloy, owing to the larger amount of contraction, cores must be made very collapsible, and liberal use of cinders or crushed coke in the interior of cores is a good

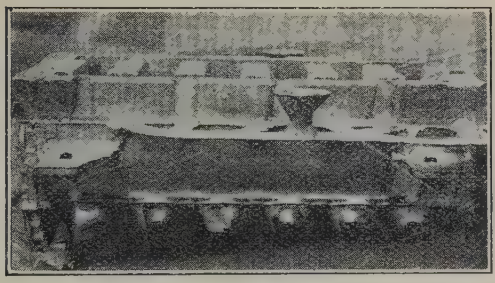


FIG. 19.—THE CASTING SHOWN IN FIG. 18 TURNED OVER TO SHOW THE RUNNERS AND RISERS.

thing. Serious thought must be given to the gating. Often if difficulty is experienced in running a casting the remedy is found in altering the gates. Sometimes it is found that the auxiliary runners may restrict contraction, causing the casting to crack during cooling.

It is desirable owing to the hot-shortness of the American alloy and " Y " alloy to break the mould and remove the casting as soon as possible, and to " knock out " the cores to prevent cracking during contraction. This point is not so important with R.R.50; quite delicate castings may remain undisturbed in the mould until cold if necessary, a distinct advantage since there is

not the fear of distortion due to breaking the mould too soon.

With R.R. 50 the runners and risers do not follow the usual practice, and the application of these important factors will best be illustrated by photographs of actual castings made at the foundry of Rolls-Royce, Limited. One feature is the general thickness of the casting; the cylinder block and crankcase generally being 0.175 in. thick, whilst the supercharger is the same thickness with webs only 0.125 in. thick; the valve-cover casting, although being the same length as

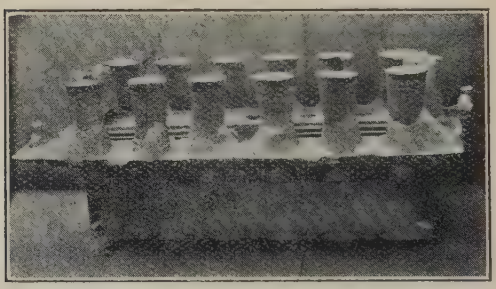


FIG. 20.—CYLINDER BLOCK AND HEAD SHOWING METHOD OF FEEDING.

the cylinder block, is only 0.120 in., this and a recent batch for some important racing engines having been made down to 0.10 in.

Some Typical Results.

Fig. 15 shows a front view of a supercharger casting, tested by air under water at 120 lbs. per sq. in.; note that only the two chills are used on the bottom face, and also the two runners. Fig. 16 shows the top face with four small plate chills only. Fig. 17 is of another supercharger casing produced without the application of any chills.

Fig. 18 is the crankcase casting, bottom side up, no chills at all being used in the production. The two runners and the risers of this are better shown in Fig. 19.

Fig. 20 shows the combined cylinder block and

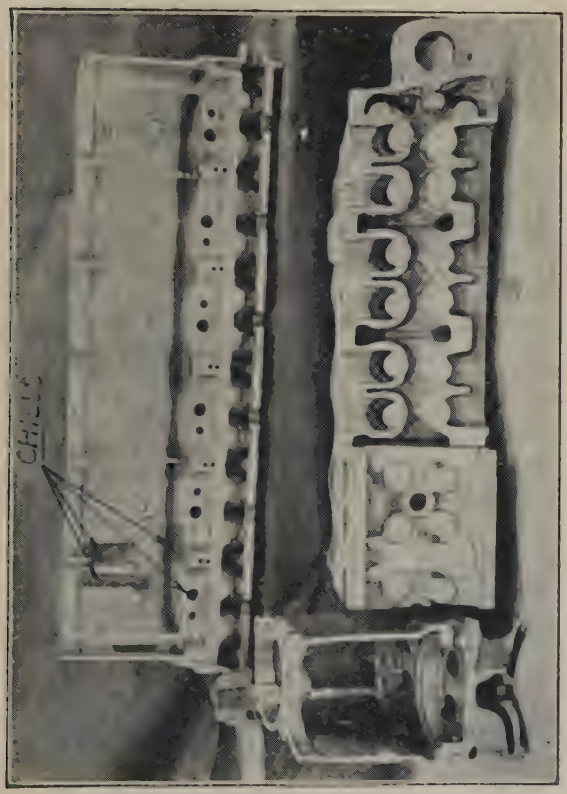


Fig. 21. Here the Casting shown in Fig. 20 has been Sectioned and Gives the Position of Chills.

head, which is tested in the water jackets to 80 lbs. per sq. in. air pressure, and 300 lbs. per sq. in. in the head. Note the feeder the whole length of the double runners at each side of the

casting. Fig. 21 shows this cylinder block sectioned, giving the position of the only chills used.

Mould and Core Dressing.

For the mould, a dusted french chalk may be used, and french chalk and water for the cores, but a very much better dressing for both mould and cores, if one has the time, is to spray, after wet dressing with french chalk and water, with a mixture of boiled linseed oil, liquid ammonia and water in equal parts. This dressing is excellent for chills, whether of cast iron, gunmetal or aluminium. In permanent-mould die casting, " Y " alloy follows the usual practice, but better results are obtainable by using in the ladling-out furnace a graphite crucible well glazed on the outside. If an iron pot be used, then it should be taken out every day and thoroughly cleaned of all dross and old dressing, and whilst at about 200 deg. C. should be coated by one of the following dressings:— (*a*) 10 lbs. of whiting and 6 ozs. of water-glass in 5 galls. of water; or (*b*) equal proportion of cement and common salt mixed into a paste with hot water. The former is preferable, but the latter is used extensively by one of the large foundries in Germany. With R.R. 50 and R.R. 53, larger runners and risers are necessary, about 25 to 30 per cent. greater than for the ordinary casting alloys. It will be found that these two latter materials are much more free from the tendency to crack and draw.

The first dressing given for the iron pots is quite good for the mould of gravity dies, but used slightly thinner, or an equal proportion of graphite, beeswax and linseed oil; for the cores a wash of graphite in water is good, the cores being dipped into the mixture occasionally, or when necessary to coat them.

In conclusion, the author expresses his indebtedness to the technical staff of Rolls Royce, Limited, for the assistance given; to Mr. Wormald for the permission to reproduce many of the photographs, and some of the sectioned castings; and also to Mr. Robinson and his own

laboratory staff at High Duty Alloys, Limited, for their work in preparing the specimens and conducting the tests.

DISCUSSION.

Mr. N. McManus, M.B.E., the Branch-President, in introducing Mr. Devereux, said they would all welcome the lecturer and appreciate his kindness in being with them, as he had only returned from Poland the previous night. They felt very grateful to him for having hurried back in order to keep his engagement. Mr. Devereux was connected with a firm which had made for itself a name for the production of high-duty aluminium alloys, and he thought that what they would hear would be in the nature of a revelation to many of them.

Thermo-Couple Sheathing.

The Chairman, opening the discussion, said that they had listened to a most interesting Paper, and many things would be quite new to some of them. A great many figures of tests, compositions and treatments that were difficult to memorise had been given, which was somewhat unfortunate, for he was sure that they could have discussed the Paper better if the figures had been available previously. Nevertheless, there was plenty of matter for discussion. Mr. Devereux had a number of very interesting castings displayed in the room, and he thought many who had examined these castings would feel thankful that they had not to make them in cast iron. In connection with the taking of the temperature of the metal, it had been explained that duplicate thermo-couples were installed, and he would like to know whether the thermo-couples were sheathed or used bare, and, if the former, the nature of the protection used. He would like to mention for the benefit of any who had not examined the castings that he had been informed by Mr. Devereux that the long core was made in sea sand. The meeting was honoured with the company of Mr. Sutton, the Chief Scientific Officer

at Farnborough, and Mr. McManus thought that they would be pleased to hear any comments that Mr. Sutton might like to make about the castings.

Melting Units for High-Duty Alloys.

Mr. Sutton expressed gratitude for the opportunity of remarking upon the Paper, to which he had listened with great interest. There was much that one could not assimilate by simply listening, and he looked forward to the time when he could peruse an authoritative copy of it. He had had many long arguments with Mr. Devereux on the matter of high-duty alloys, and he knew the difficulties to be met with in casting high-class material such as had been dealt with. There were one or two points in the Paper which had impressed him very much. Mr. Devereux had not suggested one alloy to be used as a panacea for all their troubles, and he thought that the author was right in that attitude. There were some people who stated that, if only such and such an alloy were used, all troubles would be eliminated. There was no one alloy suitable for all jobs. Mr. Devereux had not stressed all the difficulties met with in the casting of alloys, such as "Y" alloy. "Y" alloy was good for some jobs, and particularly for forging, but sand castings were very liable to be full of pinholes. Mr. Devereux had graduated in the old hard school of the foundry floor; he himself was still on it. He was wondering which factor above all others permitted the securing of sound castings in these high-duty alloys, such as "Y" alloy. Was it the melting? If so, what was the best method of melting? He thought that a great many castings were spoilt through the use of a gas furnace; coke was a little better and oil still better, but for real luxury casting the electric furnace might be used. He was interested in the heat-treatment method. Mr. Devereux had advised the use of a frozen and crushed salt bath, and he would like to question whether it was a really practical job. The British successes

in high-speed transport were a great compliment to British high-duty light-alloy castings. He personally felt very proud to-day of the British light-alloy casting industry.

Fatigue Test Results.

Mr. J. Arnott said that to anyone who was interested in such alloys, he would recommend the study of the reprint of a Paper by Mr. Devereux before the Automobile Engineers. The whole story told in the present Paper was a justification of the application of laboratory methods on a commercial scale. It was delightful to be able to see what could be done when cost was not the sole or main consideration. As a rule, the cost of the casting, he thought, was put too much in the forefront. The Paper contained so much data, some of which was entirely new to him, that he had not yet been able to digest it. He wished to refer to the fatigue tests, where he noted the results spread over a range of something like 4.4 tons. Had Mr. Devereux any comparative figures for the silicon alloy? Regarding the friction test described by the author, wherein the specimens were run against a carbon steel, he wondered why steel was used, and asked if Mr. Devereux could give any figures for specimens run against cast iron under such conditions as obtained in ordinary automobile practice.

Chills and Porosity.

He noted that the author had a great antipathy to chills. What were the objections to the use of chills in sand moulds? In the case of ordinary automobile castings, the use of chills made possible the production of castings otherwise impossible, at least that was so in the case of the silicon alloy. Was the objection due to the cost, or to the trouble of making the chills or other reasons? He confessed that he did not follow Mr. Devereux's objections to the use of chills. An outstanding feature was the high Brinell figure obtained. He hoped that the good work of Mr. Devereux and his firm would

permeate to the automobile industry where, at present, any rubbish seemed to be put into pistons. The case of co-operation between the designer and the foundry had been emphasised, but the buyer had been omitted, and the buyer was the person who should be included. When one found finished machined pistons being purchased for 5s. 6d., it was quite obvious that the buyer had been the only person concerned, and that all heat-treatment, etc., had been eliminated. It was quite interesting to note that porosity had not been the predominating feature of this Paper; in most Papers dealing with aluminium alloys, porosity and its prevention were very prominent features. He assumed that porosity was not a serious problem in the case of the castings dealt with. Had the temperature control any influence upon it, or was it due to the high-class methods used? The Paper was full of valuable information which might be summed up as the methods of the laboratory applied on a manufacturing scale, and undoubtedly that was the reason why the author's organisation had, in so comparatively short a time, become the second largest purchaser of virgin aluminium ingot for casting purposes in this country.

Sand-Blasting Reveals Unsuspected Defects.

Mr. J. Miller said he was much in agreement with Mr. Devereux's remarks about co-operation between the designer and founder. The founder nearly always wanted a little more than he had got, but he thought it could be taken as a fact that if the founder asked for more, it was a necessity for the production of a good casting. Referring to the control of the casting temperature, what type of couples was used? He noted the duplication of the couples, but who decided when and at what temperature the metal should be cast? If the metal reached such a temperature that it could not be cast to give satisfactory results, was it scrapped? Were chaplets used in those castings which seemed so thin, and were the cores held up by extension of the print? He

asked if the castings exhibited were sand-blasted. Anyone who had had experience of cast iron knew that what appeared a perfect casting before, looked very different after sand-blasting. He agreed with Mr. Arnott that it was remarkable that no mention had been made of porosity. In cast iron porosity often gave trouble and in the case of steel they certainly had more of it than they wanted. In the case of these high-duty alloys, he noted the large quantity of wax vent used, and he presumed that by this method they had overcome what might have been a great nuisance.

Mr. W. McCulloch asked if Mr. Devereux thought it essential to have such heavy risers as illustrated.

AUTHOR'S REPLY.

Mr. Devereux thanked them for the reception they had given him and for the discussion of the Paper. In reply to the President, the thermocouple used was a fairly long couple of iron-constantan, roughly 3 ft. long and covered with a steel tube to within about three inches of the end. The three inches at the end were wrapped in asbestos tape, and the actual couple was bare but dressed with a film of the dressing given for the iron pots. They lasted ten or twelve months with careful handling. The silicon alloys are all easily cast but had their drawbacks, particularly in respect to porosity. The tendency, if iron was more than 0.3 per cent., was to increase the solidification range, and during solidification crystals formed in a matrix of eutectic and gaps were left.

Mr. Sutton and himself had worked very closely together, and he had had a great deal of help from Farnborough, just as he had from the N.P.L. and other places. The National Physical Laboratory introduced the "Y" alloy, which unfortunately was so neglected by designers and the foundry in this country. It was not so in America and on the Continent, where far more "Y" alloy was used than in this country. The British people neglected it, and

he was happy in the fact that his own company did so much work on it and made it more favourably received. There were fields of usefulness for both "Y" alloy and R.R. alloys. The "Y" alloy was very difficult to use as a sand-casting alloy, and it was essential to use chills and be very particular about the solution treatment. The most important point was the ingot that was used. Actually 0.7 per cent. iron was too much, and the alloy he made contained 0.3 per cent. each of iron and silicon. The casting temperature was definitely important.

Life of Graphite Crucibles.

Mr. Sutton had raised the question of the type of furnace and fuel which should be used for melting these high-duty alloys. Coke was a very good fuel, but it was necessary to exercise exceptional care in drying it. It was also essential that a well-glazed graphite crucible be used. They obtained 60 to 80 heats from a pot when casting into ingots, and from 50 to 70 heats when heating up for sand castings. The glazing of the crucible was of the utmost importance, and his practice was definitely to discard the pot if the glaze showed the least sign of breaking. The coke seemed to cause damage to the glaze, especially if the coke was damp when charged. At the works with which he was connected, oil-fired furnaces were used with excellent results. They employed an oil of 0.95 specific gravity. He agreed with Mr. Sutton that gas-fired furnaces were liable to cause the metal to be full of gas, thus inducing pinholes and porosity. The electric furnace had not so far been developed to the stage where it could be recommended for the melting of large quantity production.

Mr. Sutton had referred to the frozen-salt bath method. It was certainly a difficult process, but a perfectly safe method of working. After a melt was done it was a nasty job to empty the salt out. The electric furnace generally was cheaper. He preferred the frozen-salt method because it was safe.

With regard to the fatigue tests, they were given only up to 40 millions; he did continue up to 100 million reversals and he had found no further drop, and this had been confirmed by McAdam in America. McAdam also said that there was no evidence of drop until beyond 200 million reversals. The R.R. alloys were much more used than any other alloy for pistons against iron as well as steel, but he had not attempted to get the actual friction curve for those alloys against cast iron.

Objections to Chills.

Mr. Arnott had asked why he had such an objection to the use of chills; there were several reasons. For one thing it was difficult to know in a sand-casting foundry when a chill was left out. One did not get consistent results, structure, properties, etc., between the chilled and unchilled portions. Chills could not be excluded entirely when it was impossible to feed properly. Where the runner and risers were not proportioned correctly, the eutectic in forming left spaces not filled, and as a last resort chills had to be used. Chills were practically essential in castings of "Y" alloy. In the case of "Y" alloy one of the troubles was that with heavy feeders they had speckiness.

Mr. Miller had asked if he had trouble from pinholes or porosity. Fortunately in the R.R.50 alloy he had not; if the alloy were cast at the correct temperature, the castings were sound. If the temperature were higher they had speckiness. The titanium, which acted as a refiner of the grain, also acted as a cleanser of the metal. He referred them to Prof. Hanson's Paper on the cleansing of molten metals.* The Brinell figures shown were not the maximum, as they could reach 160 by heat-treatment. In the case of sand castings, they could easily get a Brinell hardness of 120. If a particularly hard material were required, it was obtained by chilling. Mr. Arnott had

* Foundry Trade Journal, September 24, October 1 and 8, 1931.

said that he had left out of consideration the buyer, but that was not the case, because he had mentioned the cutting of prices, especially in England, and had said that he simply did not know how the foundry made profit on the job at the price. It was necessary to quote a fair price if any profit was to be had out of special work. There was only one possible way of making it pay at low prices, and that was to use a large amount of scrap and secondary material. They could not get castings to withstand high and severe stresses except by the use of the best materials and modern methods.

Pouring Practice.

The freezing range of the R.R. alloys was short, and in order to get sound castings they had to arrange for the solidification to take place in that range; for that reason heavy risers had to be used. In regard to the casting temperature, the question was asked who decided when and at what temperature the metal should be cast, and what happened when the right temperature was exceeded, it was the job of one man to decide when casting should take place. They had the temperature control posts distributed throughout the foundry, probably 20 yds. from where the man was working. He controlled the temperature absolutely, and worked so close that the metal was rejected at a margin of 3 deg. In the case of R.R. alloys, there was little fear of exceeding the temperature given, which was 820 deg. C. If that were exceeded, the whole of the material was taken up to 900 deg. C. and held for a time, say 15 min., and allowed to cool to near the pouring temperature slowly. If it were not convenient to do this at the time, the melt was ingotted and remelted with new metal. In the case of " Y " alloy, the metal was ingotted and remelted with 25 per cent. in new metal. Chaplets should not be used in castings of these alloys. Holes in the cylinder were utilised for the support of the cylinder cores, and a specially long print was provided for. As

to sand-blasting, only one of the specimens had been so treated. He admitted that sand-blasting would reveal defects, if they were present, which could not be seen before the treatment.

The fatigue value of the aluminium-silicon alloys, modified by the addition of sodium, was given by some authorities as $\pm 3\frac{1}{2}$ tons per sq. in. at 10 million reversals, but, of course, owing to the practical absence of any limit of proportionality, the material if stressed to the figure given would fail first by plastic deformation.

Vote of Thanks.

Mr. McManus, on behalf of the members of the Branch, thanked Mr. Devereux for his most interesting Paper, which had dealt with some materials giving, in many directions, unique results. It had given them an insight into the handling and behaviour of high-duty alloys with which they were not very familiar. The Paper had proved extremely interesting, and he asked them to accord a vote of thanks to the author for the trouble he had taken in preparing the Paper and illustrations.

Mr. Devereux, in the course of his reply, said it was interesting to note that the machines which might have been entered by Italy and France for the Schneider race had parts of the engines made of these alloys, so that had Britain been beaten in the race they would still have had much to do with the result. In thanking them he hoped that, as they elaborated the study and manufacture of high-duty alloys, he might be able to give to them another Paper.

Scottish Branch.

SAND TESTING IN THE FOUNDRY.

By W. Y. Buchanan (Member).

The title "Sand Testing in the Foundry" has a special significance, as it is intended to present the subject from the point of view of the man on the job, whose time is already fully occupied, and hence any form of sand testing likely to become a further part of his daily routine must necessarily be clear, concise and quite free from any doubt which may result in unnecessary duplicating before conclusions can safely be drawn. The following notes may be of interest at the present time in view of the fact that the official adoption of the compression and permeability tests by the Institute of British Foundrymen is under consideration. These two tests seem sufficient for foundry testing; other methods, such as elutriation, sieve-testing and others, are not referred to here.

Sand-treatment experiments were first started to try out the claims of the British Cast Iron Research Association with regard to economy in new sand and improvement in quality of facing sand, and it is gratifying to note that these claims have been justified to a surprising degree. A short description of these experiments in sand milling will show this clearly.

Milling Experiments.

The existing sand practice at the time these experiments in milling were carried out in green sand was as follows:—A mixture of 30 parts floor sand, 6 parts new rock sand and 4 parts coal dust was heaped up in alternate layers, cut vertically with a shovel, turned over and put through $\frac{1}{2}$-in. riddle. It was then sifted through a $\frac{1}{8}$-in. sieve to the usual thickness round the pattern and the mould rammed up with floor sand in the usual way.

In order to carry out milling tests a mortar mill was temporarily adapted so that the rollers could be lifted by overhead tackle. The rollers were hoisted 2 in. above the bottom of the pan,

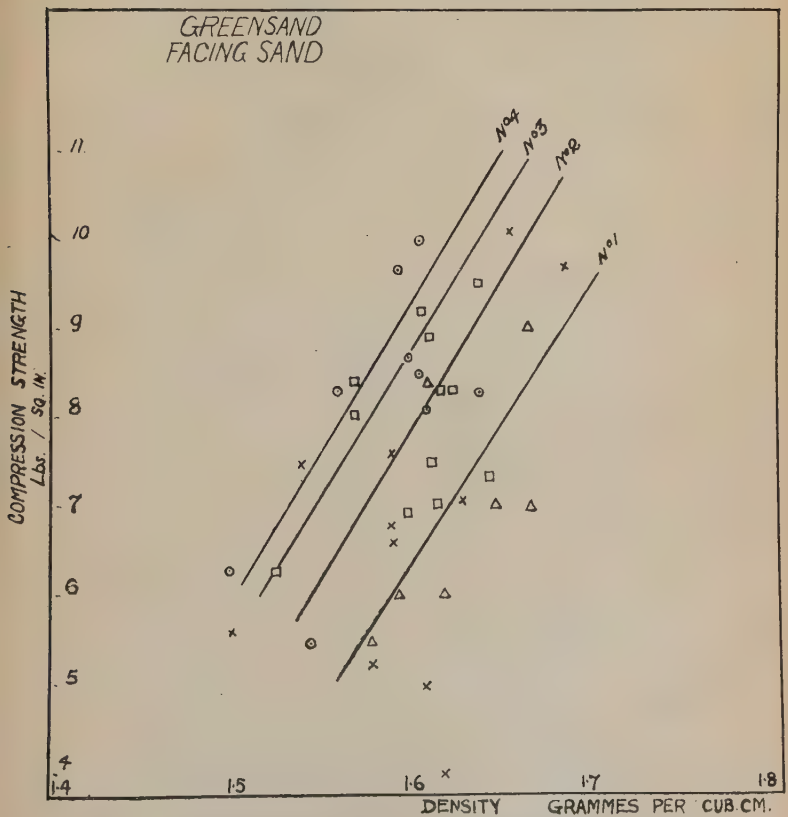


Fig. 1.—Influence of Milling on Compression Strength.

the mixture (30 parts floor sand, 3 parts rock sand and 4 parts coal dust) was shovelled into the mill. Samples were taken: (1st) when the sand had just been mixed; (2nd) when it had been

milled for 5 minutes; (3rd) after 10 minutes milling; (4th) after 15 minutes' milling. The sand was broken up in a disintegrator and was ready for use.

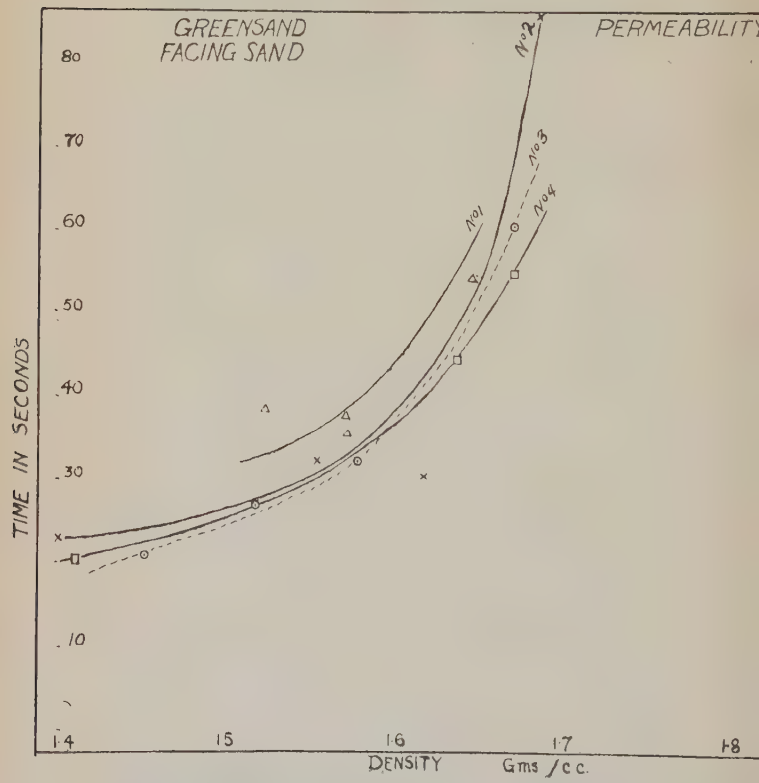


Fig. 2.—Influence of Milling on Permeability.

The graphs (Figs. 1 and 2) show that after 10 minutes' milling a 50 per cent. increase in strength was obtained and an increase in permeability and only half the usual quantity of rock sand used.

The sand was used in moulding a sand coupling. The pattern drew perfectly and the resulting casting showed very fine edges and better skin than usual. The sand in the holes was re-

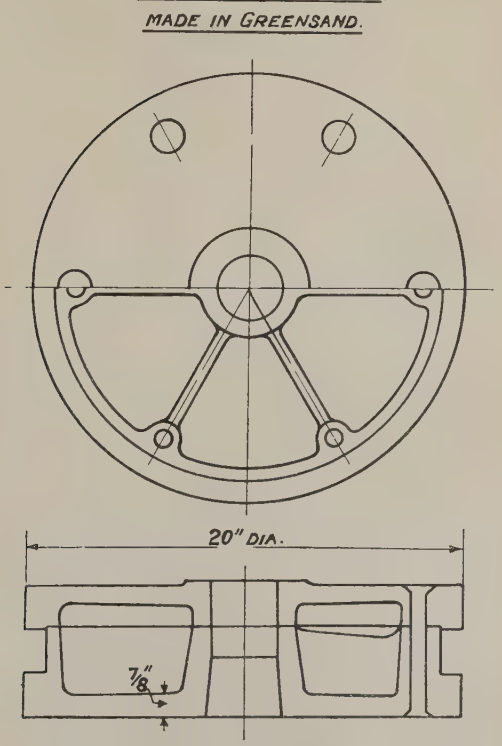


FIG. 3.—TYPE OF MOULD USED.

inforced with one sprig only. The experiment was repeated throughout with much the same result—*i.e.*, 50 per cent. saving in rock sand, 50 per cent. increase in strength, and quite an appreciable increase in permeability.

The sand was again tried out in a mould; this time for a piston cover of the form shown in Fig. 3. The previous moulding time was reduced by about a half, as the mould required less repairs and was made without sprigs or venting. The metal was cast hotter than usual

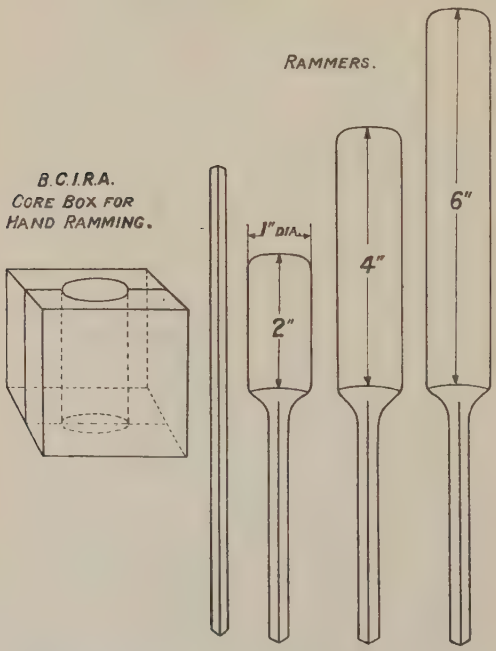


FIG. 4.—TYPE OF RAMMERS USED FOR COMPRESSION TESTS.

and the resultant casting had good edges and surface. Many other experiments were carried out but the figures just given were not improved upon. From Table I it will be seen that even with the rollers running fairly near the pan, no crushing of the sand grains is evident.

TABLE I.—*Mortar Mill with Rollers Raised. The Effect of Milling on the Fineness of Green Sand.*

Per cent. on 20 mesh.	Per cent. on 40 mesh.	Per cent. on 60 mesh.	Per cent. on 90 mesh.	Per cent. under 90 mesh.	Per cent. fineness.	Per cent. moisture.	Milling time.	Height of rollers.
15.5	12.7	29.3	19.0	13.5	56.4	9.0	5 min.	2 in.
13.7	17.8	31.2	16.0	13.5	56.5	8.7	10 ,,	2 ,,
13.7	18.7	28.0	17.7	13.7	56.7	8.2	15 ,,	2 ,,
17.2	13.1	24.0	19.7	15.2	56.0	9.0	5 ,,	1 ,,
15.0	17.0	29.5	18.5	11.0	55.0	8.3	5 ,,	½ ,,
Hard Cake taken from Bottom of Pan.								
12.0	20.0	30.0	17.0	12.0	55.7	9.0	20 ,,	½ ,,

Criticism of Compression Strength Test.

The standard B.C.I.R.A. compression strength and permeability apparatus was used in carrying

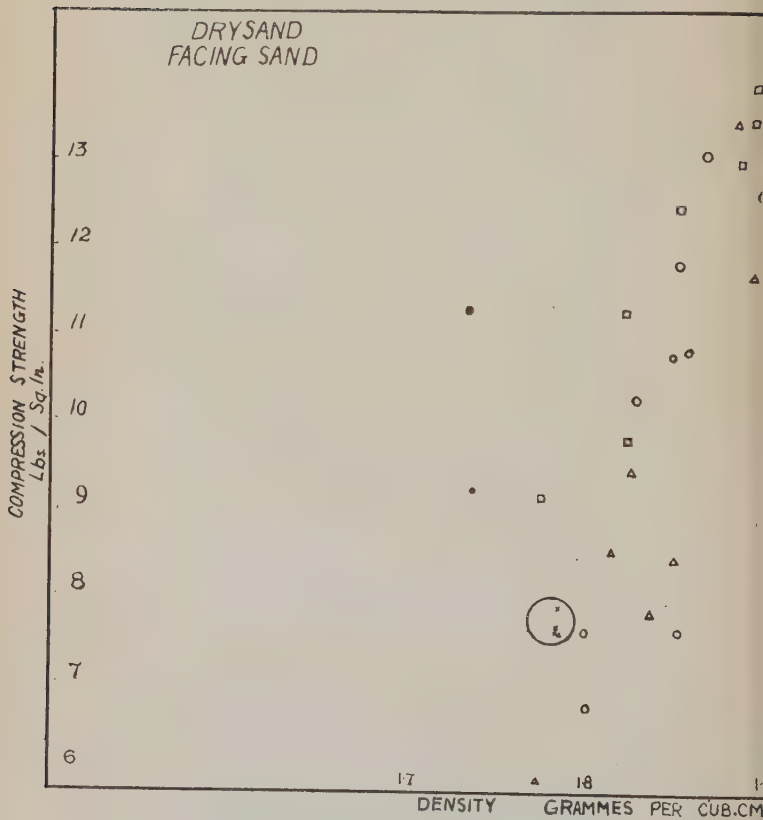


FIG. 5.—SHOWING CONCORDANCE OF RESULTS WHEN SAMPLES ARE SQUEEZED.

out these tests, and the main object of this Paper is to put forward some short methods which do not involve any change in principle,

but in the method of preparation of the test-piece before testing. The compression strength test-piece or core, being very small, was found to be the most difficult to produce. The cores always seemed to fall within a short range of densities and the difference in strength between tests of the same density often very high. Also the large number of tests done on any one sample did not give results in keeping with the time required.

In order to increase the range of these tests, rammers of different weights were made of the shape shown in Fig. 4. It was hoped to produce cores of densities varying from very lightly rammed to heavily rammed, but the results were disappointing. The cores made by hand ramming were found to break readily in removing the core box. It was then decided to try making cores by squeezing in a modified core box and the first trial gave two tests the same, one within 1/10 lb. of these and a fourth within 3/10 lb. in the dry-sand sample already tested by hand ramming. These are set out in Fig. 5.

Compression Methods for Making Test-Pieces.

The core box was made 6 in. longer than required and a good fitting plunger made to fill the 6 in. extension as shown in Fig. 6. The quantity of sand is first weighed out to correspond with the density required in the finished test-piece, transferred to the core box by way of the funnel, and the plunger pressed down to give the core its finished size. For most useful densities the plunger can be pressed down without mechanical aid, but any convenient form of lever or screw such as the compression testing machine may be used if necessary. This method is referred to hereafter as the single compression method. Some experiments were carried out on the effect of compressing the core from both ends. The first tests were done by putting a washer or distance piece of a definite thickness under the head of the plunger so as to stop the compression before it was complete, the box was

opened and the core reversed and the compression completed on what is normally the bottom end of the core. This method is hereinafter referred to as the reversed method.

In reversing the core, care has to be taken to see that sand does not prevent the box from closing, as the partly-closed box does not sup-

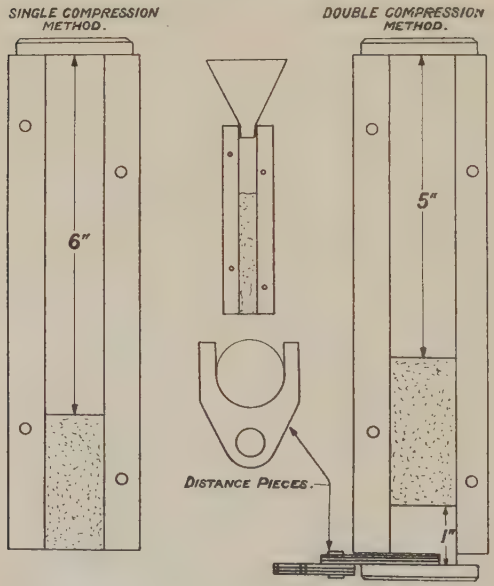


FIG. 6.—METHODS USED FOR MAKING SAMPLE CORES.

port the core during the remainder of the compression operation and a slightly strained core results. The ill effects of this are most noticeable in dry sand tested in the dry state. Hence when the core is made as shown in the right-hand part of Fig. 6 this defect is removed. The distance piece is placed in position as shown, under the bottom of the mould, and after filling

the mould the 5-in. plunger is pressed down. By turning the mould bottom up, removing the distance piece and pressing down the 1-in. plunger the double compression will have been effected without removing the core. This method, referred to as the double-compression method, is as quick as the single-compression method and produces perfect cores. The distance piece consists of some six or eight pieces of iron $\frac{1}{16}$ in. thick, so that the number of these used can be varied as required.

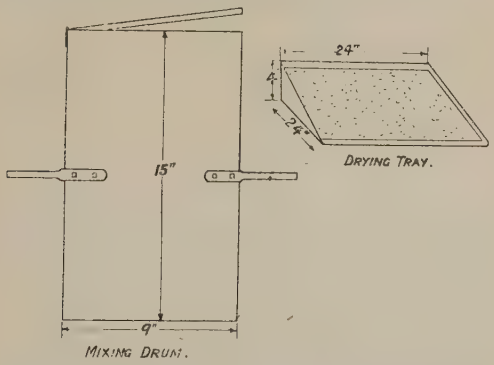


FIG. 7.—SHOWING DRUM USED FOR MIXING SAND SAMPLES AND TRAY FOR ENSURING PROPER SAMPLING.

Other possible causes of bad results in tests shown so far were thought to be: (1) Variation of the sample during casting and (2) variation of speed of loading the test-piece.

Treatment of the Sample.

The samples were always taken in airtight tins 6 in. dia. and 9 in. deep, and these were kept closed. When required for testing, the sand was passed through a $\frac{1}{8}$-in. sieve and transferred to the mixing drum shown in Fig. 7. By holding one trunnion or handle and resting the other on a low bench the drum was easily revolved so as to turn over the sample. The sand was well mixed before testing and turned over

between each test, the lid being kept tightly closed except when sand was being removed. This drum effectively cured the troubles arising from drying of the sample during testing.

The tray shown was used to prepare sand for carrying out tests on the effect of variation of moisture content. The sand was in the form of a wedge, and so the portions taken from this by cutting vertically, beginning from the thin end, gave gradually increasing moisture contents. In this way a number of samples having a variety of moisture percentages sufficient for the complete tests can be obtained after two or three hours' drying in a warm room. This was found to be much better than such methods as mixing dry sand and water, dry sand and wet sand, testing and drying alternately, and so on.

Rate of Loading the Test-Piece in the Compression Test.

To investigate the effect of variation of uniform rate of loading a pendulum was used. Taking an elevation view of the handwheel of the

TABLE II.—*Effect of Variation of Uniform Rate of Loading in Compression Test. Weight of Test Cores* 59 *gms.*

Turns of loading screw per sec.	Green sand, lb. per sq. in.	Dry sand (green state), lb. per sq. in.
1.76	5.0	—
1.20	5.6	3.1
1.03	5.1	3.2, 3.4, 3.2
0.94	5.6	3.3, 3.1, 3.1
0.84	5.9	3.1, 3.2, 3.4
0.73	5.6	3.3, 3.0, 3.3
0.62	6.0	3.1, 2.9, 2.9, 3.1
0.51	—	3.3, 3.1, 3.3
0.06	—	3.1, 2.9

compression testing machine, a point in the revolving wheel appears to move from side to side in the same way as the bob of a swinging pendulum. By keeping this point in the wheel moving directly under a swinging pendulum a uniform rate of loading was obtained. The length of the pendulum was changed and a series of results obtained. Table II shows that the

rate of uniform loading of the test-piece does not make any visible difference to the compression-test results.

The green-sand tests were carried out without the use of the mixing drum, and the dry-sand

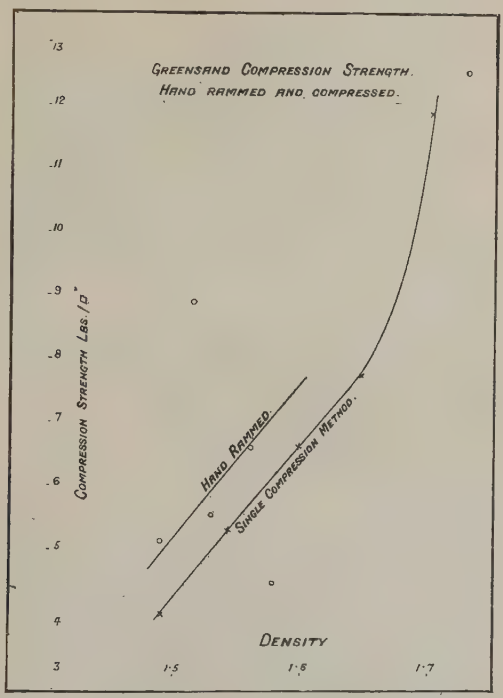


Fig. 8.—Showing that Hand-Rammed Tests give Higher Compression Results than Single-Compression Tests.

test done with the drum in use; the improvement in the results is clearly shown. Thus the use of the squeezing methods of making the test-piece in conjunction with this mixing drum makes the whole test quite free from personal

skill, and specific instructions can be given to an assistant on how to obtain this accuracy. Further, when undue variations occur under this method lack of uniformity of the sample is defi-

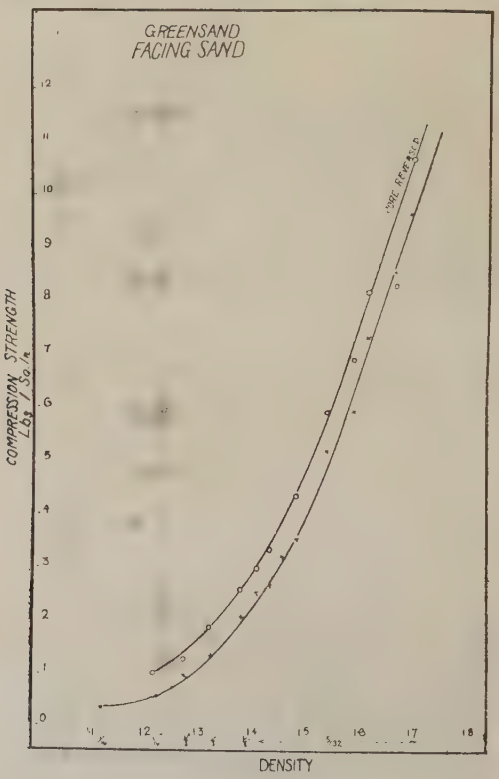


FIG. 9.—SHOWING THAT SQUATTING DOES NOT ALTER SHAPE OF GRAPH.

nitely shown. The spring balance supplied for the compression test would be much more convenient if fitted with a loose indicator as shown in the original B.C.I.R.A. illustration.

Comparison of Hand-Rammed and Compression-Made Cores.

The hand-rammed tests are shown in Fig. 8 to be stronger than cores made by single-compression method. It was thought that the

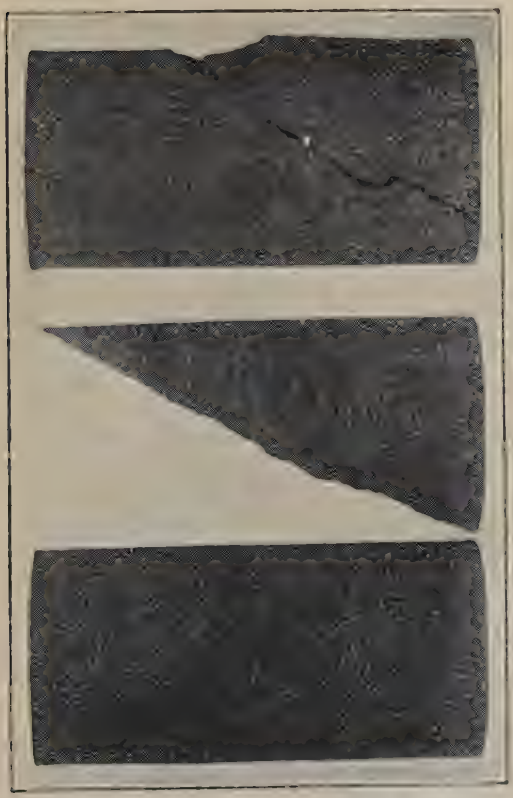


FIG. 10.—SHOWING FRACTURES OF SAMPLES WHEN USING THE REVERSED METHOD.

necessary skill had at last been acquired, as hundredweights of sand had been turned out in the form of test-cores between the time of making the hand-rammed cores shown at the beginning of the Paper and those now under consideration.

However, the second example, which was done at the same time, shows the same irregular results. The original intention with regard to the single-compression method was to use it for tests at one density only in order to eliminate the necessity for making a graph and thus complete the

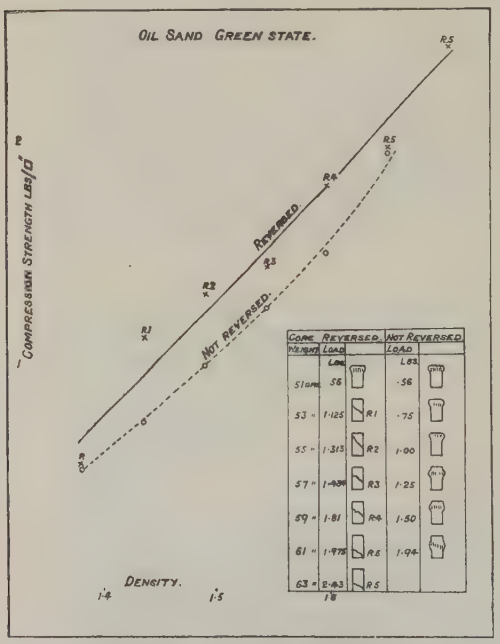


FIG. 11.—SHOWING THAT THE REVERSED METHOD YIELDS BETTER RESULTS.

test in a much shorter time, using it for daily routine tests.

The single-compression method was known to give test-pieces having soft corners at the lower end at some densities, and so, to investigate this, the shape of the fracture was carefully noted in tests made by "single compression" and also by "reversing" in various types of sands.

In green sand, squatting or bursting was observed in all single-compression tests (Fig. 9) except those above 1.5 density, but the cores withstood handling at a density as low as 1.12 and strength of 4 ozs. per sq. in. The bursting tendency does not alter the shape of the graph.

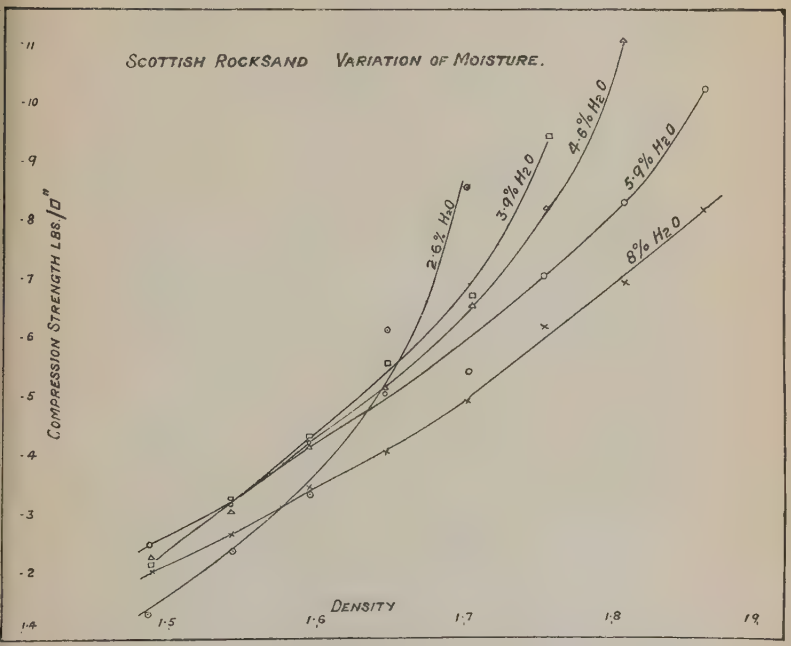


FIG. 12.—INFLUENCE OF MOISTURE ON THE STRENGTH OF ROCK SAND.

Tests made by "reversing," using a suitable thickness of distance piece, gave cores of the perfect fracture such as shown in Fig. 10.

Oil sand was tested in order to observe the effect on a finer-grained sand, and, as shown in the table of Fig. 11 all single-compression tests spread out, while reversed cores slit in the proper manner, giving higher results. The

figures R_1, R_2, etc., refer to the number of leaves of the distance piece used, each being $\frac{1}{16}$ in. thick.

The tendency of dry sand to form a hard shell on the "single-compression" made cores, when tested in the dry state, has a marked effect on the results, especially when the moisture content is high. This skin effect, which also affects hand-rammed cores, causing excessive breakages in removing the core from the core box, is due to the surface of the mould becoming wet with bonding material, and the excessive friction resulting during the actual compression sleeks the surface, principally at the top end, causing a strong shell there.

If the mould be rubbed with a dry cloth this effect is removed. The test carried out on dry sand, dry strength, show that single-compression tests crumbled and gave very much lower results than the reversed cores, which broke with the correct fracture. Oil sand in the dry state showed that single-compression test crumbled at the bottom, whilst the reversed cores slit as before.

From the foregoing tests it is seen that cores made by "reversing" are equal to the ideal hand-rammed tests, and the double-compression method has the advantage of the speed of the single-compression method with the accuracy of the reversed method without being subject to the possibility of straining if the box is not closed properly.

Moisture Content.

In all graphs shown so far the "apparent density" is the foundation on which the tests are built up, and by definition this is "weight of sand per unit volume." In the case of perfectly dry sand an increase in weight means an increase in quantity of sand per unit volume or an increase in degree of ramming. If, however, this unit volume of dry sand is moistened there is an increase in weight, hence an increase in apparent density without any change in the degree of ramming.

The B.C.I.R.A. example shows that green sand is strongest at 5 per cent. moisture and that the strength falls off with higher moisture, *i.e.*, that greatest strength was obtained from green sand "which most moulders consider on the dry

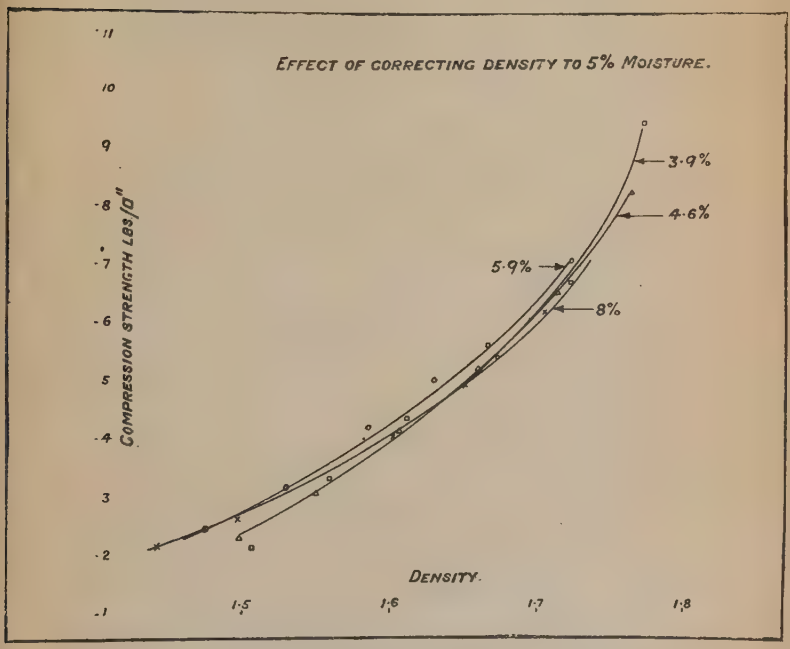


FIG. 13.—INFLUENCE OF CORRECTING DENSITY TO 5 PER CENT. MOISTURE CONTENT.

side." This did not agree with the author's experience in practice.

A sample of rock sand examined showed an increase in strength from 8 to 5 per cent. moisture over the full range of densities, and under 5 per cent. moisture the graph (Fig. 12) began to tilt sharply, giving higher strength at

high densities and lower strength at low densities.

When the weights of the test-cores were corrected to the weights they would have at 5 per cent. moisture, and the densities obtained from these weights plotted, the marked difference in strength disappeared, as is shown in Fig. 13. An example of green sand showed the same thing, one graph being roughly common to all points

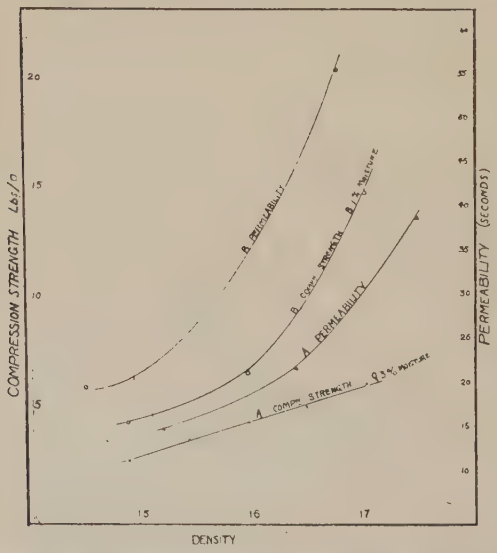


Fig. 14.—Showing the Practical Utility of Sand Testing.

after correcting to 5 per cent. moisture. A further example in green sand again showed that on calculating the densities to 5 per cent. moisture the difference in strength disappears. Thus for the same "degree of ramming," as distinct from apparent density, a moulder will get as much strength from 8 per cent. moisture as from 5 per cent., while 8 per cent. moisture makes the sand much easier to work in finishing

moulds. As a practical illustration of this effect the following example may be taken: A complaint was received of a quantity of floor sand received from the dressing shop. This sand was thought to be burnt and to have lost its

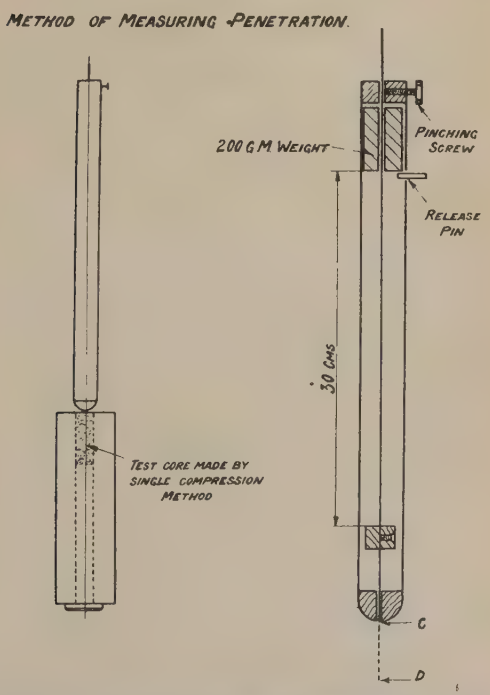


FIG. 15.—APPARATUS FOR DETERMINING THE RAMMING DENSITY OF A MOULD BY WIRE PENETRATION.

bonding power, as judged by the usual practical method. At first sight the curve A (Fig. 14), representing facing sand made from this lot of floor sand, shows a marked difference in strength from a normal quality in graph B. These curves

resemble the case just stated, and the low strength in this case is due to excessive moisture effect on the apparent density. The sand from the dressing shop would no doubt be very dry, so that the moisture would not have time to soften the clay bond and the sand would in this state show low bond strength.

On considering sand testing for the first time one naturally asks "What average density is used in the foundry and over what range are moulds rammed?" There is little use in developing sands of great strength at high densities if it is never used at or near these densities. The first attempt to find this range of densities was as follows:—A number of moulders were, each in turn, given an 800-c.c. brass cylinder to ram up and by weighing the apparatus the density of the sand core was obtained in each case. These were all done at the same time, using the same batch of sand. The variations shown in Table III are considerable when measured in terms of density. There is also, however, an intentioned variation in hardness in moulds as required by the nature of the casting to be produced. This method of finding the mould density is not very satisfactory for many reasons, and so a more convenient substitute was sought.

The degree of ramming of the sand was measured by its resistance to penetration of a steel wire under a definite blow. Penetration in millimetres when plotted against density was found to give a straight line over the usual range of densities (Table IV).

The most convenient form of this apparatus is shown in Fig. 15, the steel wire and falling weight being enclosed in a tube which acts as a guide for the wire. To calibrate the apparatus a test core is made by single-compression method, the mould turned upside. Having drawn the wire back till it is just flush with nose of tester (*c*) the apparatus is allowed to rest on the centre of the core with the wire quite free, and by releasing the weight the penetration is made. After clamping the wire in its new position the tester is removed from the core and

TABLE III.—*Comparison of Ramming of Various Moulders Making a Core of 800 c.cs. vol.*

Density.	Type of moulder.	Remarks.	Density.	Type of moulder.	Remarks.
1.600	Heavy green sand	—	1.385	Coremaker ..	Badly made.
1.600	,, ,,	—	1.535	Brass	—
1.710	,, ,,	Wet	1.410	,, ...	—
1.580	,, ,,	Dry	1.490	,, ...	—
1.630	,, ,,	—	1.580	,, ...	—
1.475	,, ,,	—	1.465	,, ...	—
1.600	,, ,,	—	1.520	,, ...	—
1.540	,, ,,	With great care	1.480	Light green sand	—
1.500	,, ,,	—	1.455	,, ,,	—
1.575	,, ,,	—	1.625	,, ,,	—
1.550	,, ,,	Good	1.690	,, ,,	Very hard ramming
1.600	,, ,,	—	1.425	,, ,,	—

Average density, 1.550.

the distance C.D., *i.e.*, the amount of pentration, measured. Cores of various densities, for example, 55 gms., 59 gms., 61 gms., 63 gms., tested in this way give a straight-line graph. The mould made of similar sand is tested for penetration and using a graph or a table of densities and penetrations, made from it, the mould density is read off.

TABLE IV.—*Comparison of Ramming of Various Moulders, using Penetration Method.*

Density.	Green sand. Type of job.	Density.	Dry sand. Type of job.
1.640	Plumber block cover.	1.720	Coupling.
1.575		1.660	
1.555		1.740	
1.558	Coupling.	1.710	Discharge box.
1.562		1.640	
1.544	Wedge block.	1.670	
1.572		1.720	
1.588		1.750	
1.588	Pump body.	1.740	Large shell.
1.526	Pump body.	1.660	
1.528	Oil ring.	1.650	
1.560	Pipe branch.	1.750	
1.560	Slide rail.	1.740	
1.440	Bedplate.		
1.480			
1.490	Hopper.		
1.490	Shell segment.		
Average density, 1.544.		Average density, 1.71.	

If the test sand used to produce this graph is normal in moisture content and quality a very good idea of the average density will soon be got as the actual test on the mould takes a few seconds.

Table IV shows the type of results obtained. The average for green sand agreed with that obtained by the previous method 1.544 against 1.550. The variation in the same mould is shown clearly by this test and problems raising the question of hardness of ramming in specific parts of moulds could be investigated in this

way. A neat round hole $\frac{1}{8}$ in. dia. is made in the mould face and this might quite well be left unrepaired.

A separate calibration graph is required for each type of sand, *i.e.*, dry sand, core sand, oil sand, and the time required to make the graph is 10 to 15 min. Reversing the core dur-

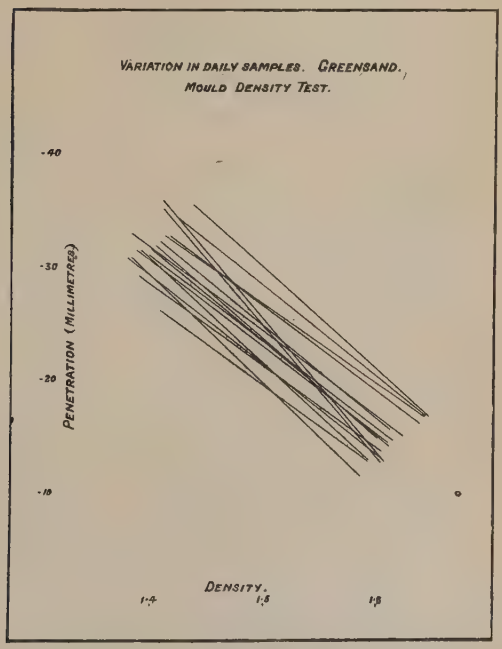


FIG. 16.—DAILY VARIATION TESTS MADE BY THE PENETRATION METHOD.

ing compression is not necessary to ensure accurate results, because the softness of the lower end of the core when it does exist is mostly round the edges while the penetration takes place down the centre. A test done on dry sand which as stated earlier is most liable to softness

at the lower end in single-compression cores shows here 1½ mm. difference at most.

The provision of several weights, say 300 gms. 200 gms. and 100 gms., is useful, as for example in the case of oil sand a very light weight is necessary. It is, of course, best to use the

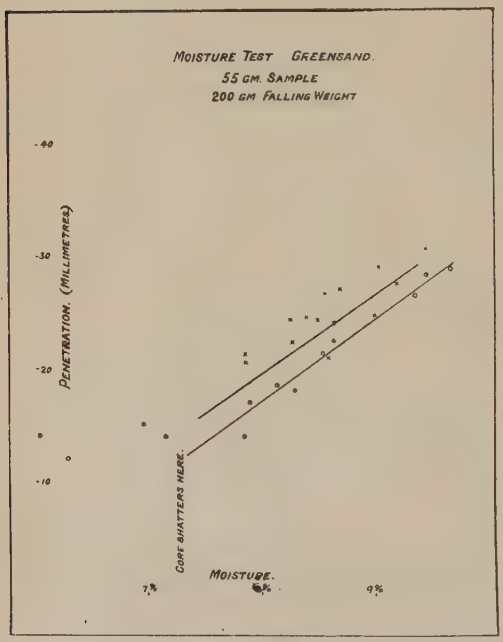


FIG. 17.—SHOWING THE USE OF PENETRATION APPARATUS AS A MOISTURE METER.

heaviest weight which will suit the type of sand to be treated in order that the reading may be as large as possible. There appears to be a direct relationship between the weight used and the penetration. As the densities used in this test are apparent densities the method is subject to moisture effect already described.

A number of these calibration graphs in Fig. 16 show the variation which was noted in daily samples over a period. This variation suggests a method of determining moisture referred to later. If the milled sand is controlled by some

Fig. 18.—Effect of New Sand Additions on Strength of Facing Sand.

type of "moisture meter" or other device this difference will not exist, but tests will be perfectly accurate if made on moulds made from the same sand as that used for calibration.

In order to use the density testing apparatus as a moisture meter advantage is taken of the

difference between degree of ramming and apparent density. The procedure is the same as in making a calibration graph except that one density only is used and the moisture is varied by drying the sand in stages. The

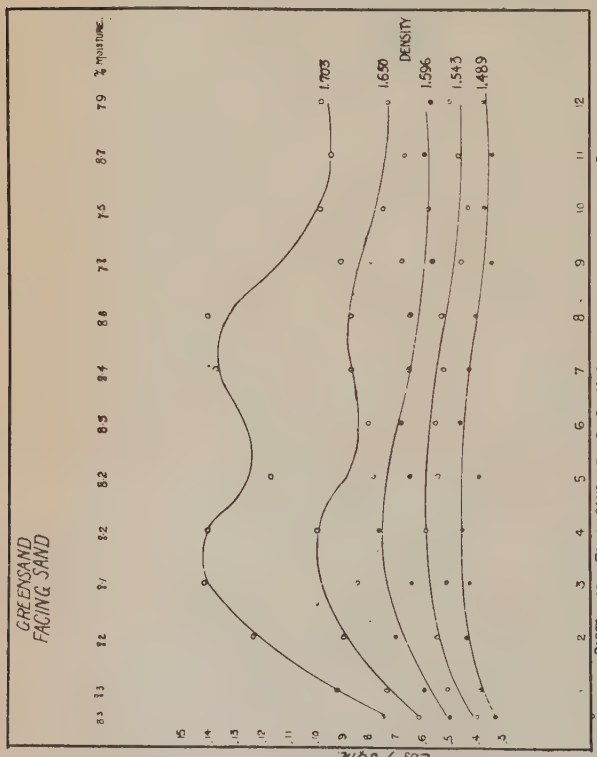


FIG. 19.—SHOWING HOW RELATIVELY SMALL ADDITIONS OF NEW SAND ARE EFFECTIVE.

moisture by evaporation, and penetration test at the agreed density, are carried out at each stage in drying. The lower line in the graph Fig. 17 gives the moisture by this method and the points represented by circles give the results by evaporation method. The agreement in a

single sample is therefore very good. Taking samples at random from the mill, the graph was moved upwards to the second position and the points represented by crosses indicate these results. The error is higher, due to the influ-

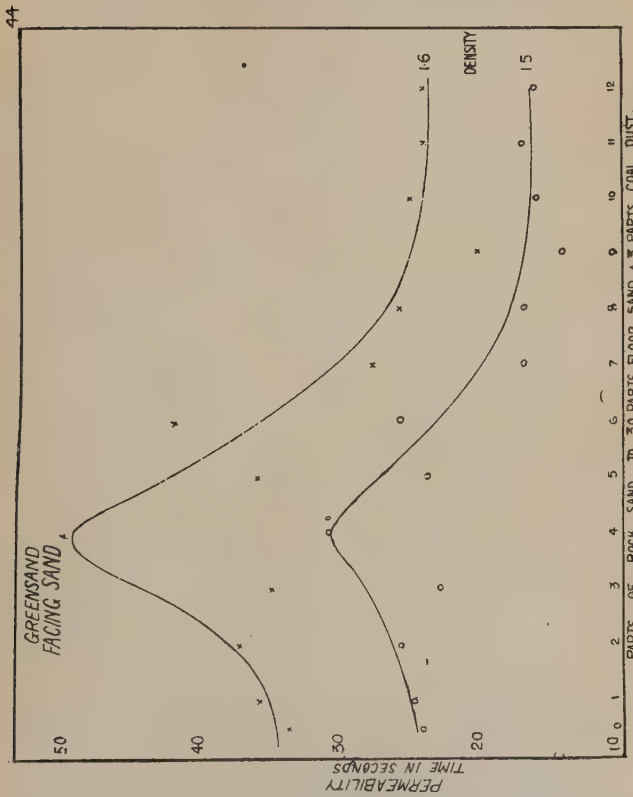


FIG. 20.—PERMEABILITY IS AT A MAXIMUM WITH MODEST ADDITIONS OF NEW SAND.

ence of the many factors which come into play in the foundry. Thus if sand is produced having a penetration value of 24, the variation of moisture should not exceed 0.7 per cent.—*i.e.*, 8.3 to 9 per cent. The accuracy to be expected in dry sand appears to be much the

same. It appears that the actual bond strength of the sand does not affect the penetration value.

For daily moisture control the sand mix-

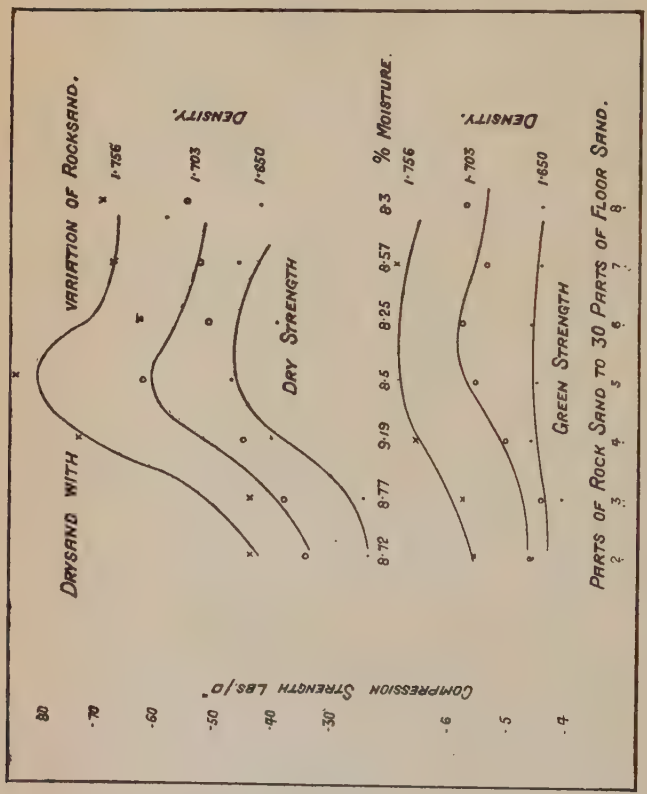


FIG. 21.—SHOWING STRENGTH DECREASING WITH THE HIGHER ADDITIONS OF NEW SAND.

tures would be made to have a specified penetration value, a higher value would indicate too much moisture and a lower value the opposite. If the sand is put into bins in horizontal layers and removed by cutting vertically as in the

previous sand practice the moisture variation will be reduced accordingly.

Effect of Variation of New Sand.

The object in view when starting out to investigate the effect of additions of new rock sand to

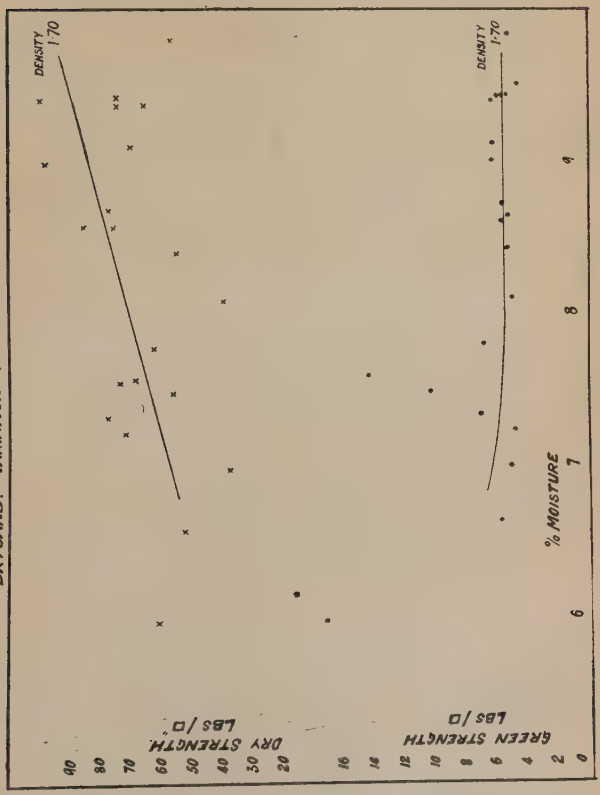

DRY SAND. VARIATION OF MOISTURE.
DENSITY 170
DENSITY 170
% MOISTURE
DRY STRENGTH LBS/□"
GREEN STRENGTH LBS/□
40 30 20 16 12 10 8 6 4 2 0
6 7 8 9

FIG. 22.—SHOWING THE STRENGTH OF DRY SAND IS HIGHER WITH INCREASING MOISTURE.

facing sand was to draw up a table giving the properties of each mixture and to express these briefly, as, for example, 6-35 sand or 7-40 sand, when the first figure would give the compression strength at the average moulding density and

the second figure the permeability at the same density and 10 cm. gas pressure. The idea was to use these special sand mixtures for specific types of jobs. In the graphs (Fig. 18) for variation of rock sand, note the regular shape of the

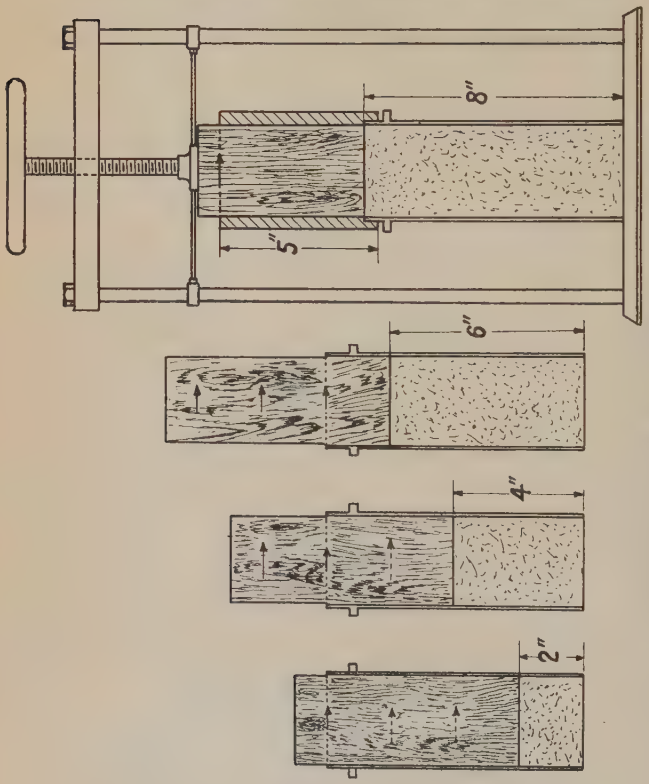


FIG. 23.—SHOWING THE RAMMING OF PERMEABILITY TEST CORES BY STAGES.

curves made by single-compression method as compared with results previously obtained by hand-rammed cores.

The same results represented in a different manner indicate that at or near 1.55 density (the average foundry moulding practice) the greatest

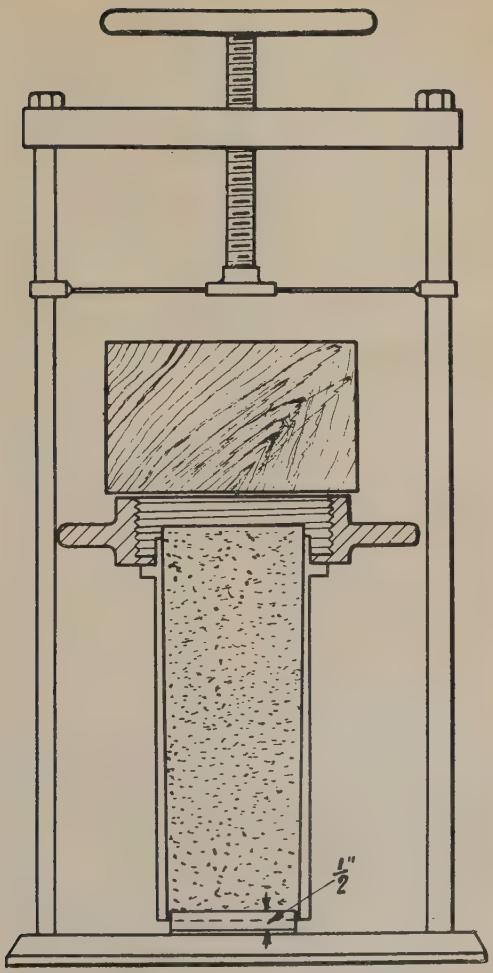


FIG. 24.—SHOWING METHOD OF REMOVING PERMEABILITY CORE FOR DRYING.

strength is reached at 4 parts rock sand to 30 parts floor sand. Thus the high rock sand additions erroneously used to give great strength in the facing sand, some of which were at least 12 parts rock sand, are not only wasteful but actually reduce the strength to that obtainable with 1 part rock sand to 30 parts floor sand. This is shown in Fig. 19.

The permeability curves were also plotted from tests got by hand ramming as described in the B.C.I.R.A. directions and from these curves the two curves shown in Fig. 20 were constructed. The sand is least permeable at 4 parts rock sand and then becomes more permeable with high additions of rock sand. Testing dry sand showed that the maximum strength was obtained at 4 parts rock sand in the green state and similarly in the dry state.

These graphs can be plotted directly without first making a curve for each sample tested, as is required with hand-rammed tests, and this shortens the time required.

A repeat set of tests strengthens this conclusion regarding rock sand addition. If rock sand, as received, is tested for compression strength and permeability it will be found to have low strength and high permeability, and thus when present in excess it tends to impart these properties to the facing sand (Fig. 21).

Moisture Variation on Dry Sand.

A number of daily samples tested at 1.7 density indicate that at moisture range usually found green strength is not affected, but that dry strength is decidedly higher at the high-moisture content (Fig. 22). The question of time required in drying would, of course, be kept in view when deciding on what moisture content to use in the foundry.

Permeability Test.

The B.C.I.R.A. method for permeability is again hand ramming, but in this case, since the test-piece is very much larger, there is not the same difficulty, and rammers of various weights

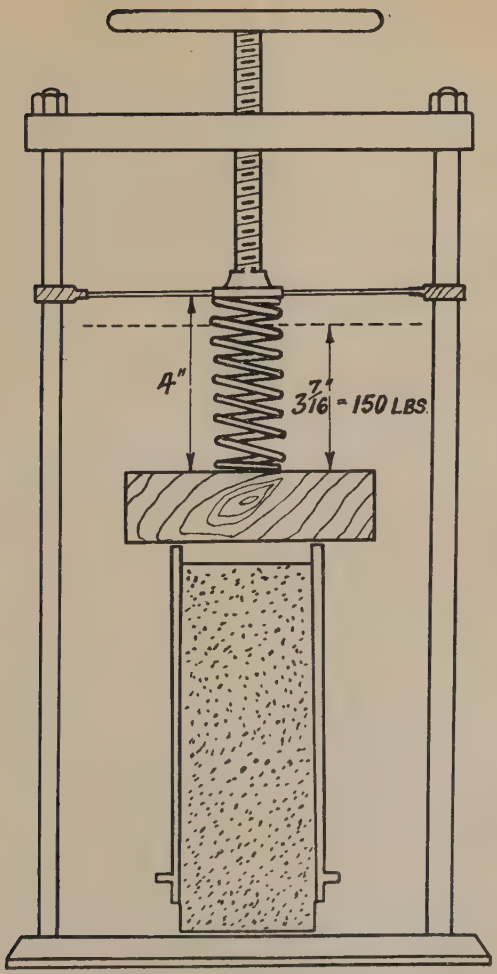


FIG. 25.—SHOWING HOW THE DRIED CORE IS REPLACED IN THE BRASS CYLINDER FOR THE PERMEABILITY TEST.

were used quite successfully in this case. However, for daily tests this means making a graph for each sample, and requires a large sample of sand. As in the case of the strength test, a compression method was applied. Fig. 23 shows the method. It was obvious that ramming all at once was quite unsuitable, and so it was decided to do so in several stages, as shown. The weight of sand corresponding with the required density was divided into four equal parts. These were transferred to the cylinder and compressed one at a time, using a marked plug and the testing machine frame to complete the pressure. To catch the loose fourth lot of sand, an extension was slipped over the end of the cylinder, and a plug again used to produce the finished core. The extension and plug lifted away, left the core ready for testing.

Thus, the core had a definite density, and daily tests done in this way compare without further trouble. This method is quite suitable for green-sand testing, the total time required for one test being about 4 min.

In dry sand the permeability test done in the green state may be of little value, since the sand is dried before use, and it is therefore desirable to understand what happens on drying. The method adopted for testing dry was as follows: A brass cylinder (Fig. 24) was made, having a difference of $\frac{1}{16}$ in. in the bore from top to bottom, the mean diameter in the middle of the cylinder being the same as before. This gave a slight taper, but maintained the volume as before.

After ramming up either by hand or compression, the core was removed, as shown in Fig. 24. A disc of the size of the small end of the core was placed under the core, so that, by pressing on the cylinder, the core was gently loosened. The coupling, a part of the permeability apparatus, serves to transmit the pressure of the screw evenly round the cylinder.

After drying, a thin sheet of paper was placed round the core and the cylinder replaced (Fig. 25). The final pressure was controlled by

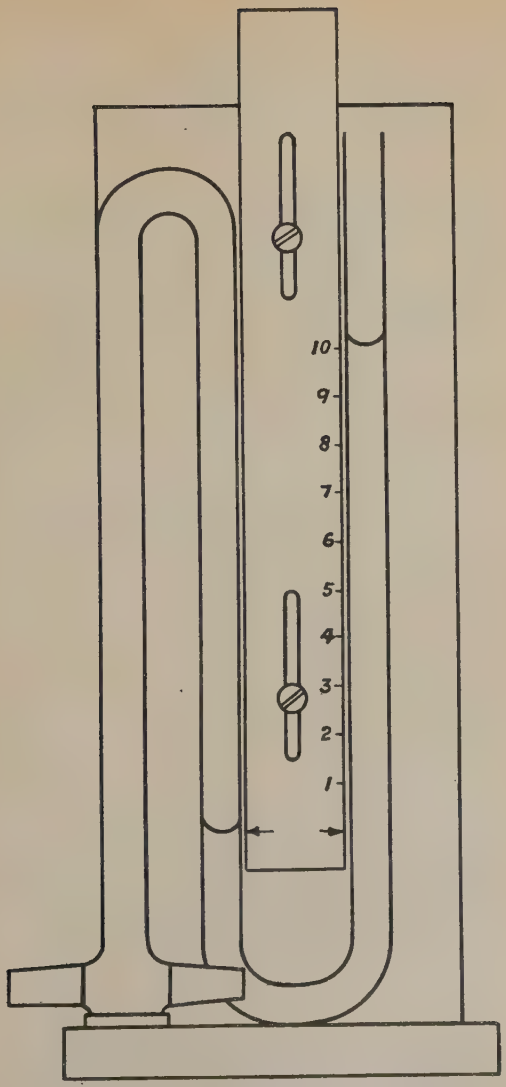


FIG. 26.—TYPE OF MANOMETER USED.

a calibrated spring, not because this was necessary in the permeability test, but because the distance which the core moved towards its original position in the cylinder gave some definite idea of the change in volume during dry-

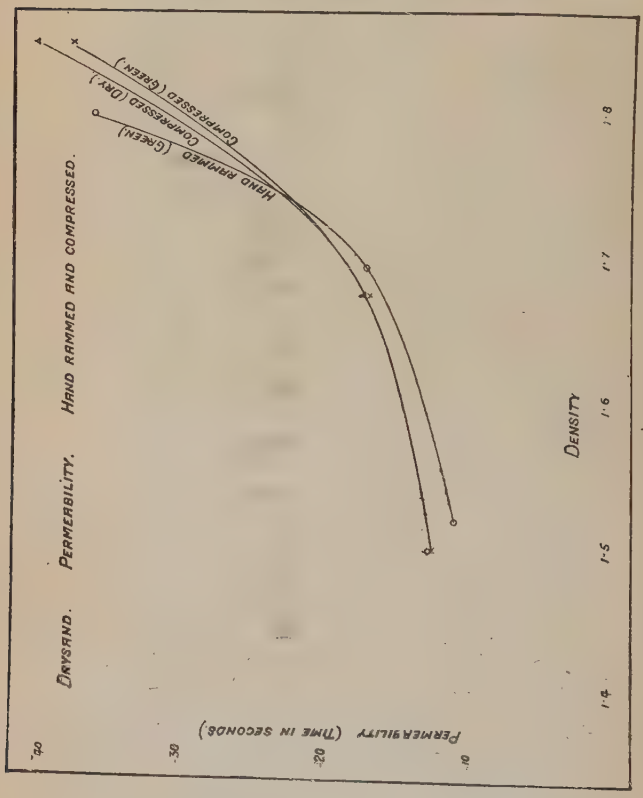


Fig. 27.—Showing the Negligible Difference in Permeability when Hand-Rammed and when Compressed Specimens are Used.

ing. Very little has been done on this question as yet.

The permeability test carried out on this dried core gave a very clear idea of the effect of drying, and had the great advantage of being ex-

pressed in exactly the same terms as the green permeability.

The measurement of time was taken from the start of the gas flow through the core till the instant of the first appearance of flame,

FIG. 28.—TYPE OF MILL INSTALLED AS A RESULT OF THE EXPERIMENTS DESCRIBED.

generally in the form of a small explosion which marks a very definite instant of time in contrast to the time when the gas begins to burn quietly. Readings of time were invariably taken at both the first explosion and time of quiet

burning, and an attempt was made to find a simple relationship between these times, without success. The time of explosion was corrected to what it would be at 10 cms. gas pressure.

The manometer shown in Fig. 26, which reads one way, was found much more convenient to

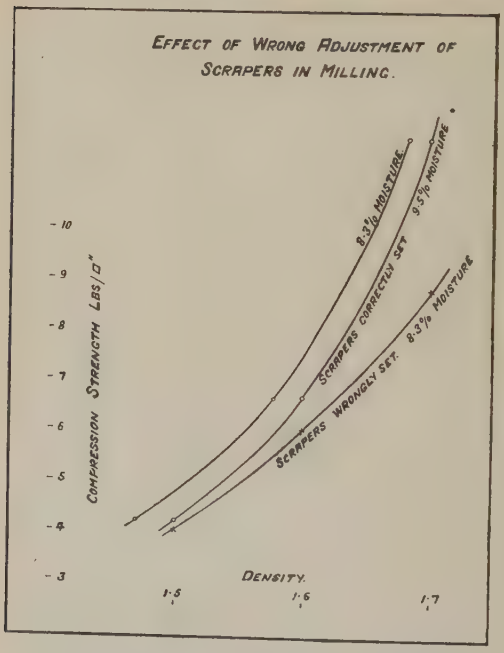


FIG. 29.—EFFECT OF THE ADJUSTMENT OF SCRAPERS.

use than that supplied with the apparatus, and an accurate reading of the gas pressure is advisable. In dry-sand tests by compression, each layer or portion of sand should be raked up before the next is added, in order to prevent a parting forming between the sections. Cores made and removed as described can be pressed

out of and into the cylinder a number of times without showing any signs of damage.

The density figure used for a dry core is that of the same core in green state. In Fig. 27 the hand-rammed green and compression-made green permeability tests are shown to differ very little. The compression-made cores were dried and retested, and again the change in permeability due to drying is seen to be practically nil.

Description of Milling Plant.

From the results obtained with the temporary arrangement the firm decided to put in a sand mixer. The mill installed (Fig. 28) is a well-known type having a stationary pan, with revolving gear carrying the rollers and scrapers, and a disintegrator fitted into the discharge shute at the bottom. The rollers are free to rise and fall, and there is ample provision for adjusting the scrapers as well as the height of the rollers above the bottom of the pan.

In the background is shown a portable sand thrower, which is used in this case to keep the mill supplied with floor sand. The sand, after being moistened, is aerated and mixed by this machine and thrown up in good condition. The floor sand, rock sand and coal dust is shovelled into the mill, and, after allowing five minutes from the time at which the charging is complete, the mill is emptied. A barrow, run under the discharge shute, catches the milled sand which is run into the green-sand bin on the right-hand side, the dry-sand bin being on the left-hand side. The mill is situated in the centre of the foundry between the columns separating two bays and the bins are accessible from both sides. Barrows are used here because crane handling is not very convenient.

Working.

About 35 shovels of sand were found to be the best load for the mill. The parts requiring attention are the scrapers. If these are allowed to wear very much, the sand sticks to the pan, forming a hard cake, which increases the wear

on the scraper and at the same time puts extra load on the driving motor due to excessive friction. The scrapers should be used only in their original positions; interchanging, so as to reverse the wearing parts, may seriously reduce the efficiency of the mill. Fig. 29 illustrates this point—*i.e.*, a decided increase in strength is shown after correcting the scrapers.

It is best to make an accurate pattern of each of the scrapers when these are first received and to cast new ones ready for replacement. The scrapers should be adjusted every few days as required and light oiling of the inside of the pan will help to prevent the sand adhering and building up into a cake.

Results Obtained.

The foundry " returns " show that before sand milling was introduced 1 ton of rock sand was used in the production of 5.4 tons castings, whereas since sand milling has been carried on 1 ton of rock sand is used to produce 11.1 tons castings. This saving of roughly 50 per cent. rock sand is in itself sufficient justification for the installation of milling plant, and sand testing properly carried out beforehand should indicate that economy is possible with sand treatment. Notwithstanding this substantial economy in new sand, the greatest saving should be obtained in wages on most types of light work, especially when this is done in plate-moulding, as here the value of the sand used is a very small fraction of the wages expended, and an increase in bond strength has a pronounced effect on the time required repairing moulds.

The author is deeply appreciative of the permission accorded by the Mirrlees Watson Company, Limited, Glasgow, for their kind permission to publish these notes.

DISCUSSION.

The Chairman (Mr. N. McManus, M.B.E.), in introducing Mr. Buchanan, said the question of sand selection and preparation had not received so much attention in British foundries

as had been given to it in America. There had, however, been an improvement in recent years, and foundrymen had realised the necessity of giving more attention to sand problems. He thought that the first real study in Britain was by Prof. Boswell, who, at the instance of the Ministry of Munitions, had investigated the available British sands. Mr. F. Hudson had investigated Scottish moulding sands, and Mr. Oliver Smalley had also done much work on British sands. At the conclusion, he said that they had listened to an excellent Paper, and he thought that they were all very indebted to Mr. Buchanan and should express their appreciation of his efforts to produce the Paper. The time devoted to the work and preparation of the graphs, etc., must have been very great. They had been given an enormous amount of data, and it was somewhat difficult to appreciate them all simply by listening to them. They would appreciate them better when they saw them in print. He felt sure that there were a number of points which they would like elucidated and many questions to be addressed to Mr. Buchanan, which he felt sure the author would be only too pleased to answer.

Sieve Tests.

Mr. D. Sharpe said that after all the multitude of figures which had been put before them, it might appear rather impertinent to ask for more, but he would like to ask Mr. Buchanan to give them the results of sieve tests on the sands which had been dealt with, not perhaps in great detail, but specially in regard to the amount of fines. He personally put great stress on the proportion of fines in a moulding sand.

Mr. Buchanan replying to Mr. Sharpe said he was sorry that he had no sieve tests on those sands. He had done a great many sieve tests and in some respects they appeared quite useful, but he had books full of figures for which he never had much use except in the case of sharp sands where it was useful to determine the amount of fines after use or for passing on a

complaint to the suppliers. He had a certain amount of difficulty in regard to screening tests because there seemed to be so many different screens that it was difficult to know which to use. He really could not add anything useful on sieve tests.

Permeability Tests.

Mr. F. Hudson said that he thought Mr. Buchanan was to be congratulated upon the excellent Paper he had produced and the very careful manner in which he had gone into the sand question in the foundry with which he was connected. He had been specially interested in the author's remarks regarding the permeability testing by the British Cast Iron Research Association's apparatus and the difficulties of obtaining reliable results. He himself could confirm what Mr. Buchanan had said about the unsatisfactory tests on hand-rammed cores. He had not been familiar with the Research Association's apparatus chiefly because he had worked with his own apparatus for a good many years, but about two months ago he thought it would be as well that he should become familiar with the Cast Iron Association's apparatus and purchased a set with the object of comparing the results with those obtained with his own apparatus. He regretted that he had been unable to obtain any reliable results with the Association apparatus. Mr. Buchanan's figures confirmed his own experience and showed the absolute unreliability of the British Cast Iron Association testing apparatus. He had had an assistant doing nothing but sands for more than a month and he could get no results at all with hand ramming, the variations were from 71 to 108 with a density of 1.6 and 149 to 186 with a density of 1.7. He thought Mr. Buchanan's Paper would be of real value to anybody attempting to use the British Cast Iron Association apparatus. He would like to ask Mr. Buchanan about the permeability of dry sand, the method and the modification. In making tests with his own apparatus he had

found a great difference in permeability between the sand green and after drying. Was there any possibility of a leakage between the cylinder and the core after it had been returned to the tube? He rather thought there was such a possibility. He thought Mr. Buchanan might give an opinion as to the use of coal gas for testing permeability. His experience had been that from the time the gas was turned on and the production of a steady burning flame there were one or two explosions and the explosions must form a vacuum in the top part of the container. If Mr. Buchanan gave them his opinion on these points he thought it would greatly increase the value of the Paper.

MR. BUCHANAN replied regarding the difference between the sand for dry-sand testing green and dry, and the possibility of a space being left between the core and the sides of the cylinder and allowing gas to pass that had been kept in mind, in fact it was the first thing to look for. His first tests were done by rapping and as far as he was aware there was no escape of gas up the sides. Every precaution was taken in checking. If the sand was very much more permeable in the dry state there should be a great reduction in the time the gas took to pass through. As both were much the same, there could be no escape, if there was they would have a lower time.

MR. HUDSON said he found that the permeability was greater after drying in the ratio of 100 to 150.

MR. BUCHANAN: Did you find a change in volume?

MR. HUDSON: Oh, yes.

MR. BUCHANAN said the tests he did showed hardly any change in volume.

MR. HUDSON: Was moisture condition constant?

MR. BUCHANAN said it was; hence he used a calibrated spring. He thought that any slight change of volume would be shown very clearly by the length of the core. The taper on the core was very slight and a small change in volume

should produce a considerable movement in the cylinder. A great deal more investigation was needed and the results which he had given were not very old. He had no doubt that in the near future a better apparatus would be devised.

Mr. A. Lawrie said that he had been exceedingly interested in the Paper, but there had been so many figures and diagrams given that he had not been able to assimilate them. He had, however, gathered one or two impressions. Regarding the proportions of the sands given by Mr. Buchanan, he would like to point out that floor sand was not a standard material and it all depended on the composition of the floor sand what proportion of rock sand was added. As the sand deteriorated the rock sand had to be increased. It might be that 40 to 45 tons of floor sand were used to 1 ton of rock sand, according to the work done. The floor sand in his foundry was a very different material from the floor sand in Mirrlees Watson's foundry. With regard to the variation of permeability due to ramming, he thought that was bound to occur unless they worked to a standard length. He would expect that one end of the core would be more dense than the other and the permeability figure would be that of the denser end. If rammed from both ends the core was liable to be softer and more permeable in the middle. Regarding dry sand and the relative permeability in green and dry state, the core should be more permeable in the dry state. In the old days the usual test for permeability was to dry the core and weigh it, then immerse it in water until saturated and then reweigh. The weight of water absorbed gave a working idea of the permeability. He thought that on the whole Mr. Buchanan had broken new ground. In the old days founders got on very well without the need for so much testing, and he was inclined to think that in those days better work was done than now. He was, however, very pleased that it should all come about for the good of the industry.

Mr. Buchanan said that the whole aim of the

work done for the Paper was to show that sand testing was not necessarily a highly scientific operation, but that it could be made a mechanical thing which any two persons could do and get the same results. As to the query whether sand testing would benefit the industry, he would mention that the sand they made in their foundry in the mill described was used for all classes of castings made by the firm from small couplings to bed plates 25 ft. long in dry sand, covers for evaporator ends, 8 ft. dia. swept in green sand. All those were made with one sand mixture. Of course, for one class the mixture gave very good results and others not quite so good. The mixture he had mentioned did not give quite such good results with light castings as with heavy ones. They could not make a sand for each class of castings, it would take up too much time. The whole object of the tests he had made was to find a type of sand which could be used for all the work in their foundry. Regarding Mr. Lawrie's reference to floor sand, no doubt it was anything but uniform. Although it might vary greatly, it would be fairly uniform after milling. The adjustment of the floor sand was the whole object of sand testing. If there was no testing method, the moulder played for safety and added more rock sand than was necessary. Regarding variations in the test-piece, he took pains to verify it before putting the matter to Dr. Skerl, and many of the points which he had put forward were in answer to his criticism. Then if one part of the compression test-piece was soft all the tests were the same, and results comparable and quite useful. If the test-pieces were made as he had suggested there would be no variations. Regarding permeability of the cores, since they were not used for strength testing, the necessity for uniformity was not so great. The appearance of the cores were much superior to anything he could produce by hand ramming.

Sand Testing and Economies.

The CHAIRMAN said that they were pleased to welcome Mr. Semple, one of the directors of

Mr. Buchanan's firm, and he thought they would be pleased to hear what that gentleman thought of the results obtained from Mr. Buchanan's work.

Mr. D. Semple said that he really had not enough knowledge to talk to a body of foundrymen about sand testing. It was really so short a time since they took up the work on sand preparation that it was very difficult to say much. He thought Mr. Buchanan had produced very good results and a distinct economy. Since adopting the milling and mixing process they had effected a very large reduction of repair work on the moulds. The whole object was to help the production of castings. They were really only at the beginning of the job, and if any of them could offer suggestions for still further advancing the usefulness of the work they would be glad to adopt them.

Mr. J. Longden said that he had been greatly interested in the Paper and more especially in the graphs showing permeability. He was not sure that he understood what Mr. Buchanan wanted to convey by the graphs. He noticed that the permeability curve rose with increasing time. When speaking of permeability he was not sure whether the author meant to convey increasing release of gas or the contrary. He could hardly see how there could be an increase of permeability and an increased time. It was interesting to note that 5 per cent. water gave the maximum strength and other properties. He was obliged to Mr. Buchanan for all the valuable data he had given.

Mr. Buchanan said perhaps he should have explained the graph for permeability a little more fully. The scale showing time in seconds should be read the opposite way. High time means a low permeability and a short time a high permeability, so at first sight the graph appears to be wrong. Milling produces no ill effects unless great pressure is used. The rollers can be allowed to run on the bottom of the pan. The only drawback to milling is that the sand

dries slightly quicker in the air. When sand is mixed with the shovel small particles of rock sand the same size as the holes in the riddle are formed, and these contain their own moisture which does not dry off so quickly. In milled sand this excess bonding material is spread over a larger area.

The PRESIDENT said that he would like to say how greatly indebted they were to Mr. Buchanan for the excellent Paper, which contained so much interesting and informative material. They were also indebted to Mr. Hudson for his remarks on hand ramming of the test cores. At his own works they had a Cast Iron Research Association testing apparatus, but had done very little with it on account of the difficulty of getting reliable results, and had put it aside. However, with the lead that had been given by Mr. Buchanan and Mr. Hudson, he hoped they might yet be able to do something with the apparatus. The Paper had been tremendously interesting, but it was so full of charts and figures it was not easy to assimilate it. They would, however, be able to appreciate it better when they saw it in print. He asked them to express in no uncertain manner their thanks to Mr. Buchanan for the trouble he had taken in preparing and presenting the Paper.

MR. BUCHANAN said that he was obliged for the vote of thanks and the kind reception of the Paper. If anything he had said had been helpful or interesting he was very pleased.

Sheffield Branch.

THE HIGH-FREQUENCY FURNACE AND ITS USE FOR THE MANUFACTURE OF STEEL CASTINGS.

By T. R. Middleton (Associate Member).

It is natural that a great departure from recognised melting practice should at first attract much criticism, and the high-frequency furnace was no exception. Five years have now elapsed since such furnaces were made available for the melting of steel on a commercial scale, but controversies still wage on various questions, and doubts are still prevalent regarding the electrical and metallurgical efficiency of this newer type of melting.

On the one hand, we are told that a certain furnace has exceeded all expectations; that the melting cost is comparable with that of the arc furnace, while the quality of steel produced is superior to that previously melted in the crucible. On the other hand, some steelmakers claim that the coreless-induction furnace cannot replace the crucible, since the steel produced in the latter is so much the better quality; they also state that the high-frequency furnace cannot compete with the arc, with regard to either price or quality, and that the necessary electrical equipment is the source of constant trouble, likely to cause prolonged stoppages owing to breakdown.

There is no doubt that until the melters became proficient some inferior steel was produced in the induction furnace, as was the case with all other melting processes when first introduced. Melting costs may have been high, due in part to incorrect charging of raw materials, to poor refractories and to inefficient control of electrical plant, which itself may not have been perfect.

What is the present position, and how far have the early expectations of designers and users of these furnaces been justified?

Survey of Development.

The furnace which was introduced by Dr. Northrup in 1916 could scarcely be regarded as a commercial melting unit. Current at a frequency of about 20,000 cycles per second was produced by means of a mercury-gap oscillator. The furnace consisted of a refractory crucible surrounded by a coil which was connected to the source of energy, and the circuit was tuned by means of a bank of condensers. Furnaces of this type have a very low power factor, and condensers are necessary to correct it. The maximum power available from a mercury spark gap is of the order of 50 kw., so that only small melting units could be employed. Such furnaces as are in use to-day would be found chiefly in research laboratories, although one commercial application was the production of carbon-free nickel alloys such as Permalloy and the melting of rare metals.

It was later found that, for larger furnaces, the operating frequency could be considerably reduced, and that the current could be supplied from a synchronous generator. Such generators became available in 1925, and in 1926 the first Ajax-Northrup foundry melting unit, operating at 2,000 cycles per second, was installed in America. During the following year a similar furnace was installed in Sheffield, and a little later a Metropolitan-Vickers furnace, operating at 500 cycles per second, was put down at the Vickers works of the English Steel Corporation. Since that time numerous furnaces have been installed in this country and abroad. In England there has been no demand, probably on account of the bad trade conditions, for furnaces of over 600 lbs. capacity, but in France furnaces ranging up to 25 cwt. in capacity are operating successfully. As regards the design of larger furnaces, there are no technical difficulties in the construction of 10- or 15-ton units, and in this

connection it is interesting to note that a 4-ton furnace is now being built in this country for use in Sweden.

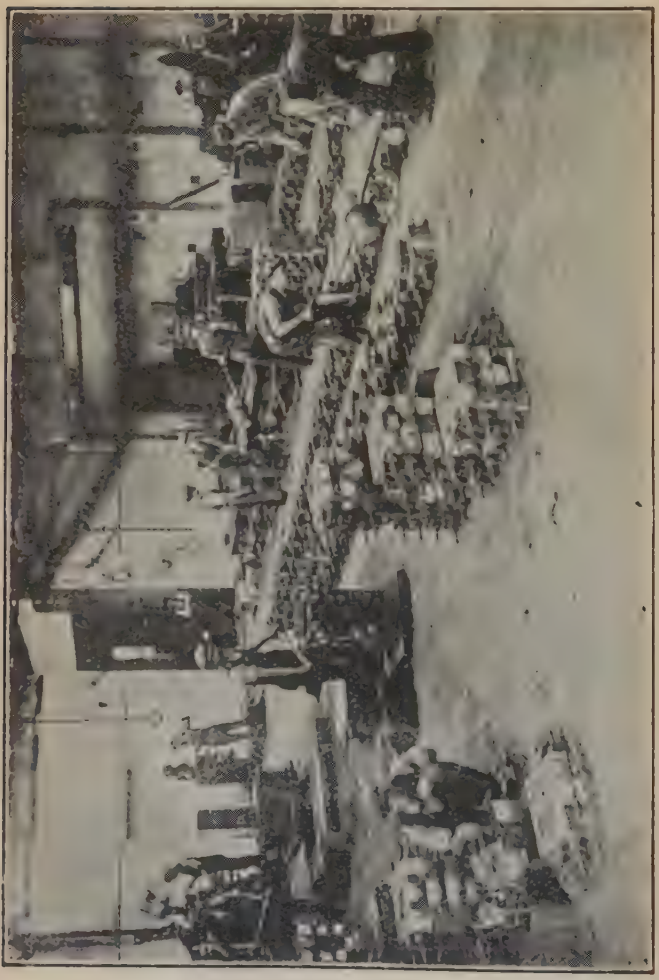


FIG. 1.—A CORNER OF THE SPECIAL STEEL FOUNDRY, ENGLISH STEEL CORPORATION.

Such furnaces as are now in use operate at frequencies of between 500 and 2,000 cycles per second. A typical unit—a 5-cwt. furnace—in use at the works of the English Steel Corporation is shown in Fig. 2. The furnace is supplied with current by a 160-kw., 500-cycle motor-generator set which is housed in a building immediately behind the furnace stage, where are also the necessary banks of condensers.

After the motor generator has once been started, the equipment is controlled by the melter from the control panel, on which are situated the generator oil-switch control, voltmeter, ammeter, reactive k.v.a. meter and push-buttons for switching condensers in or out as required. Control is simple, but the indicators on the panel must be watched continually and the necessary adjustments made during the course of melting or otherwise the result will be a poor load factor and melting time will be prolonged. The efficiency has been further improved in the more recent equipments by the addition of automatic control gear.

Large Furnaces.

Progress during the past four years has been good, but the development of larger furnaces has not been so rapid as one could have hoped. Great improvements have been made in the design and efficiency of motor-generator sets, which have effected a considerable saving in power. In 1927 the overall generator efficiency was about 60 per cent.; modern 150-kw. generator sets have an overall efficiency of about 80 per cent., while larger generators are still more efficient. The power consumption per ton of steel melted in the older furnaces was from 900 to 950 kw.-hrs., while with modern equipments the figure may be as low as 650 kw.-hrs. per ton in the 5-cwt. furnace and still lower in the larger types.

Improvements have also been effected in the design of the furnace unit. In the earlier types the inductor coil was clamped to wooden uprights and the whole housed in a wooden box.

Such units were unsatisfactory, since they were easily damaged and warped with the heat, and it is clear that, especially for larger furnaces, a stronger construction is necessary. The obvious framework would be one made of steel, but the

Fig. 2.—A 5-cwt. High-Frequency Induction Furnace.

stray field is such that if proper precautions are not taken the various members would be heated by eddy currents to a considerable temperature. Several types of construction have been adopted, one of which consists of a framework made of

non-magnetic steel, the various members of which are arranged, with regard to the strength and direction of the stray field at all points, so that heating by induction is reduced to a minimum. The whole frame is covered with asbestos slate. There are other methods of construction by means of which the stray field may be limited to a definite path, and which would allow the furnace casing to be built of ordinary structural steel plate. One of these consists in surrounding the coil with several packs of laminated transformer iron, while in another the whole of the inside of the casing is lined with $\frac{1}{4}$-in. thick copper sheet.

There have been other improvements, all of which help to make the modern high-frequency furnace a most efficient melting unit. Condensers for the larger furnaces are now of more robust construction and are water-cooled; the coil design has been modified, as, for example, in the Northrup furnaces, where a graded coil has resulted in a more uniform field which reduces end losses, and heats the charge more uniformly from end to end.

Refractories.

Refractory materials for the lining of high-frequency furnaces have received considerable attention. The pre-burnt clay or plumbago crucibles, which were so very unsatisfactory and had an average life of only five heats, have been replaced by linings built up by other methods. Of these the sintered lining, which may be of acid or basic refractory, is the type most generally used. In preparing the lining, 2 to 3 in. of suitably graded refractory is first rammed on to the furnace bottom, and on this is bedded a hollow mild-steel cylinder having its bottom end closed. The space between cylinder and coil is then carefully rammed with refractory up to the level of the top of the coil, the furnace top and spout being finished off with brick and ganister or by any other suitable method. The procedure then consists in charging raw material into the cylinder and melting down slowly; the refractory

is thus sintered and bonded to the form of the cylinder. Such linings are very satisfactory; they are quickly prepared and last for many melts. Rammed linings of ganister have lasted

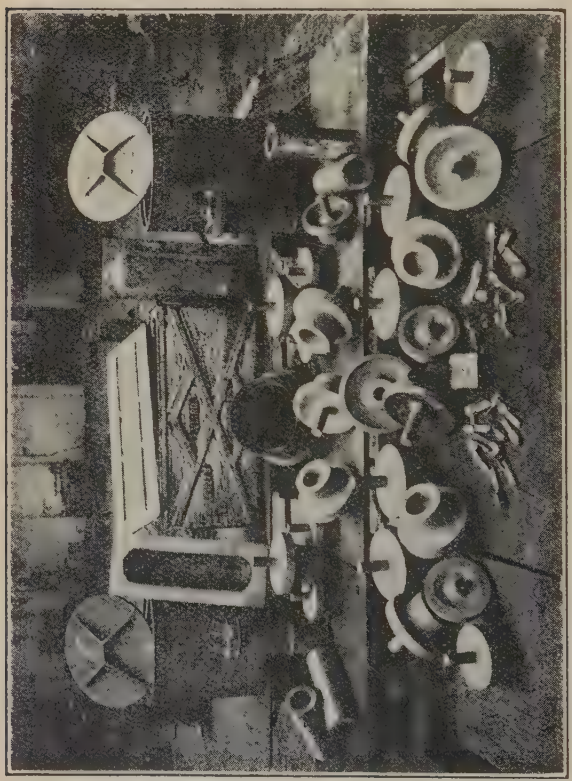


Fig. 3.—Stainless and Heat-Resisting Castings.

in some cases for over 70 heats, the average being about 55 heats.

Another type of lining which has been recently developed is that built up of unburnt silica or magnesite bricks. The bricks are of special section, having tongue and groove joints, and

are generally built into place without cement. There is a small space between brick and coil which is packed with refractory sand, and the top of the furnace may be finished off as in the case of the rammed lining. These bricks are at present being used with considerable success—silica linings lasting for 70 or more heats and magnesite in some cases over 100 melts. The average life is about the same as that of the rammed lining.

Many arguments have been put forward both for and against the high-frequency process of melting, and it is interesting to deal with some of these in detail, in the light of experience gained over the past three years, during which time nearly 7,000 casts of steel have been produced in the 5-cwt. furnace at the works of the English Steel Corporation.

Reliability.

It has been said that generators producing current at the high frequencies required are unreliable, and foundrymen will look upon the necessary electrical gear with doubt, especially if they have not available a competent electrical staff. It would be futile to argue that breakdown will not occur; but generators have been running for some years with no more attention than one would expect to give to any high-speed machine, and in the case of that at the Vickers works, stoppages due to repairs to electrical plant have been under 2 per cent. of the available working time—surely a not unreasonable proportion. If the motor-generator set is housed in a well-ventilated building, kept free from foundry dust, and is used with consideration, there is no reason why any excessive trouble should be experienced. The condensers have given good service and few replacements have been necessary. With regard to the furnace unit, there is little to cause breakdown, and such mishaps as have occurred may, except in some extraordinary circumstances, be put down to carelessness in one form or another. The fact that molten steel is surrounded by a

water-cooling tube may be looked upon with apprehension, although the chance of water coming into contact with molten steel is very remote. In one instance, owing to the furnace bottom being not properly made up, some of the

Fig. 4.—Castings in Heat-Resisting Steel.

sand lagging leaked out, and during the heat the crucible cracked, allowing the molten steel to come into contact with the coil. It was found that no damage had been done either to the furnace or to the coil.

It has been claimed by some sceptics that oxidation losses in the high-frequency furnace are so great, particularly in regard to carbon, that it is impossible to make any steel, to any specification, with certainty. This is far from being the case, although one might be forgiven for predicting high oxidation losses in a furnace with so great a bath turbulence and such ready access to the atmosphere. The height to which the bath wells up in the middle is about 2 in. in the case of a 500-cycle 5-cwt. furnace, and is about 1 in. in the 2,000-cycle unit. It is true that some carbon is lost, and the percentage loss is very nearly the same as in the crucible process; but whereas in the crucible carbon losses are very irregular, it is found that, in the induction furnace, losses may be controlled, and that it is possible to work to narrow ranges of analysis. Table I shows the carbon percentages obtained in 12 consecutive heats of five different steels.

Steels Nos. 1 and 2 were of low-alloy content, and Nos. 3, 4 and 5 were steels of high-alloy content. Alloy losses in melting are low, and it is possible to melt high-alloy scrap with little change in analysis. Table II shows the chromium losses during melting of four different steels.

The remelting of manganese-steel scrap does not present any difficulties in a basic-lined furnace, and melting losses are not high. The following results were obtained in remelting three heats of scrap:—

	C per cent.	Mn per cent.
Calculated	1.20	13.60
Analysis obtained ..	1.11	13.18
	1.135	13.38
	1.11	13.18
Average loss ..	0.081	0.35

The high-frequency furnace has thus a decided advantage over other melting processes, it being possible to remelt, for example, stainless-steel scrap, with very little loss of chromium and no

TABLE I.—*Carbon Losses in the H.F. Furnace.*

Steel No.	Specification, C per cent.	Calculated. C per cent.	C per cent. obtained.						Average C loss per cent.
1	0.70—0.74	0.84	0.675	0.695	0.72	0.70	0.715	0.755	0.13
			0.715	0.705	0.70	0.72	0.70	0.73	
2	0.65—0.70	0.81	0.67	0.70	0.70	0.695	0.69	0.665	0.13
			0.68	0.69	0.67	0.665	0.68	0.68	
3	0.35—0.45	0.44	0.41	0.38	0.37	0.41	0.40	0.385	0.05
			0.39	0.40	0.37	0.38	0.35	0.39	
4	0.30	0.33	0.32	0.29	0.295	0.295	0.31	0.29	0.03
			0.31	0.285	0.31	0.33	0.29	0.30	
5	0.175—0.225	0.20	0.19	0.195	0.185	0.20	0.19	0.205	0.005
			0.22	0.19	0.19	0.22	0.185	0.20	

carbon pick-up. There is no loss of tungsten or molybdenum, as is experienced in the arc furnace on first heats, and, owing to the circulation of the metal in the furnace, one obtains thorough mixing.

The induction furnace suffers one set-back in its competition with the arc furnace in that, working at frequencies such as are at present usual, large quantities of scrap turnings cannot be melted efficiently. The operating frequency determines the size of scrap which may be melted, the smaller the charge the higher the necessary frequency. In a 500-cycle furnace, for example, the charge should consist of pieces having a diameter of not less than about 1.50 in., if it is to heat up efficiently. This does not mean that no smaller scrap may be used. It is rarely that an ideal charge of scrap is found, and the efficiency with which the heat melts down depends upon the way in which the melter charges the scrap into the furnace. In order to fulfil the best heating conditions, the largest pieces should first be placed in the furnace, spaces being filled in with smaller scrap, and the smallest scrap should be added when the rest has started to melt.

Refining Difficulties.

The attention of metallurgists has for some time been given to the question of refining in a high-frequency furnace. There is no doubt that refining can be carried out, and, owing to the circulatory motion of the bath, slag reactions are extremely rapid. One advantage of induction heating is that the heat is developed in the metal itself, but this is a disadvantage so far as refining is concerned, since the slag is only heated on the underside by the metal bath, and in order to keep a fluid slag it would be necessary to have an auxiliary source of heat. Personal opinion is that the high-frequency furnace can, at present, be best employed in the melting of raw material and scrap of reasonable purity, and that refining, though possible, would not be an economic process.

TABLE II.—*Chromium Losses in the H.F. Furnace.*

Steel No.	Calculated Cr. per cent.	Per cent. Cr. obtained. Three heats.			Cr. per cent. loss. Average.
11	26.80	25.60	25.75	25.87	1.06
12	17.50	16.84	16.64	17.24	0.59
13	13.30	13.28	13.08	13.02	0.17
14	6.10	6.04	6.00	6.06	0.066

High-frequency melting is exceedingly rapid, and large weekly output is possible with quite a small furnace. The length of time taken to melt a charge will depend on several factors; different steels require different procedures, and the time for "finishing" a heat will vary according to quality and to the melter's judgment. A 5-cwt. furnace is capable of melting a charge in 1 hr. or under, and, including charging and casting times, will average 1½ hrs. per heat.

Non-Ferrous Melting.

So far as non-ferrous alloys are concerned, it is only for the production of those with high-melting points that the coreless induction furnace has been used. Alloys such as brass and bronze are melted far more efficiently in a low-frequency ring-type furnace.

At the time of its introduction, the high-frequency furnace received more attention as a melting unit which was to replace the older crucible process, as a means of producing tool steel, than as a furnace for melting all types of steel required in the foundry. It was not long, however, before the users of these furnaces realised the possibilities of this new method of melting.

Foundry Applications.

It was found that the quality of steel produced was good; melting costs were comparable with arc furnace practice; losses of alloying elements in melting were low, and casting temperatures could be accurately controlled. Here, then, was a furnace which could be tried out, in the first place, to replace the crucible furnace for supplying steel to the small "special steel" foundry, where castings of the heat-resisting and magnet varieties were made. The advantages gained were immediately recognised, and in the English Steel Corporation foundry all castings of this description are made with high-frequency steel. The melting costs were halved, and the quality of casting produced was improved. It was

possible to obtain 5 cwts. of steel of one analysis, instead of taking a number of pots from the crucible furnace, all of which might vary in analysis. Subsequent heat-treatment of castings was therefore simplified. The quality of steel produced was as good as and, in some cases, better than could be made consistently in the crucible, especially magnet steels.

As an improvement on the crucible process for the production of special steels for castings, high-frequency melting has been a success, but to be of great use to the foundry world, it must go much further than replacing the crucible. It will be asked how far the induction furnace can replace, or augment, the open-hearth and arc furnaces in the large steel foundry. So far as cost is concerned, Siemens steel is so much the cheapest that, where the quality is satisfactory, and where a sufficient weight of steel can be dealt with at any one time, induction and arc-furnace steels are definitely precluded. So, at the present time, the high-frequency furnace may be regarded only as a competitor of the arc furnace in the large foundry.

Unfortunately, the works in Sheffield have been compelled to carry out experiments and tests on a much smaller scale than has been done elsewhere, but the indications are that production and quality of steel melted in the larger H.F. furnace is equally as reliable as, and in some respects better, than in the 5-cwt. furnace.

Melting Costs.

As regards melting costs, the 5-cwt. furnace turning out 20 tons per week produces steel as cheaply as a 30-cwt. arc furnace, and the 1-ton furnace, with a weekly capacity of about 80 tons, melts rather more cheaply than a 4-ton arc. For intermittent working the induction furnace is definitely the cheaper, since there is no great bulk of refractory to heat up.

Although melting costs may be about the same, the relative costs of steel made by the two processes will depend on the type of steel to be melted, which will determine the class of raw

material to be used. Carbon steel may be produced more cheaply in the electrode than in the induction furnace, since the former can absorb far greater quantities of steel turnings. In the medium alloy grades of nickel and nickel-chrome steel, etc., the electrode furnace is still rather the cheaper. In the case of steels of high alloy content, such as the various chromium and nickel-chromium, stainless and heat-resisting alloys, production is made cheaper by using the induction furnace, especially where alloys of low-carbon content are being made.

The high-frequency furnace at the Vickers works has produced steel of all types for the foundry, including low-carbon, various nickel-chrome steels, and manganese steel, in addition to the various special qualities already mentioned. The quality of castings produced has been entirely satisfactory. Tests taken on these castings have been good, and there is no reason to doubt that the furnace is capable of successfully producing any class of steel which may be required in the foundry.

In the small steel foundry the induction furnace is invaluable. Even a small furnace is useful in the large foundry for castings which are a little out of the ordinary analysis and will not absorb a whole heat of electrode steel; also for the production of steel for those special and experimental castings which could not otherwise be made conveniently. In spite of the success with which this furnace has met, it is not thought that the time has yet come when it would be advisable or economical to equip a large foundry solely with this type of melting unit, the arc and open-hearth furnaces having in some cases such a decided advantage as regards cost of steel in the ladle. It is, however, a most valuable accessory, and when the merits of coreless induction melting are fully appreciated by foundrymen no large foundry will be considered complete without its one or more high-frequency furnaces.

Wales and Monmouth Branch.

LIGHT-CASTINGS PROBLEMS.

By G. Moran (Member).

Though problems of the light-castings industry cover a wide range, practical, technical, economic and administrative, yet in many essentials they do not differ from the heavier or allied casting trades, being characteristic in their elements, methods of production and scientific principles. Customers have to be satisfied that production charges which govern selling prices are reasonably economic—then they are firmly impressed that any business can with assurance be safely left in the hands of a foundry. They realise that, as regards quality, service and price, when both parties are satisfied, one half of the industrial battle is already won, and outside competition is not then sought. To attain this desirable consummation, which is by no means improbable and in fact is often achieved, requires careful thought, concentration and attention to detail.

The following remarks represent the view of the jobbing founder, who undertakes all kinds and quantities, of innumerable variety and mixtures, and whose experience, consequently, is more widespread than the specialist in one line, whom he envies in this respect only.

There is probably more of interest, technical and practical, in the founding industry than in any other profession; its essentials are so numerous and varied, its ramifications and applications so wide there is scarcely any trade which does not rely upon its products for some important feature and in some shape, size or form.

There are so many channels for scope: the *foundry proper*, and its endless variety of castings of all sizes and sections; *core-making*, green and dried, sea-sand and sharp; *sand-mixing* (a fine art of boundless possibilities); *pattern-shop practice*, the interpretation of drawings and blue prints; *cupola practice*, the charge and mixings, linings, daubing, suitable fuel and correct proportion for economic purposes, tapping and casting temperatures, ensuring sound products, each constituting vital problems for due consideration

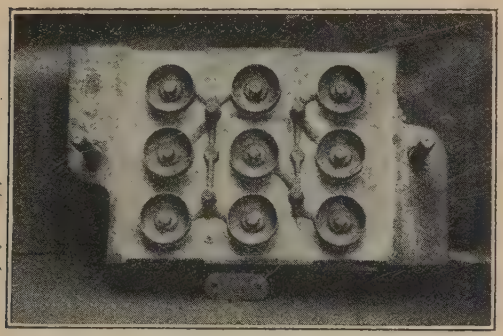


FIG. 1.—PLATE-PATTERNS FOR MACHINE MOULDING.

Keen perception, knowledge and understanding of one's fellow workers are essentials; that is, treating everybody in the concern as one of the family, working *with* you and not *for* you. Half the troubles of the existing generation are a lack of appreciation of the sterling qualities of the finest workmen in the world, far too many of whom were compelled through lack of opportunity to migrate to foreign lands, forming the nucleus of opposition instead of co-operation. It is best to fix prices and adhere to them. If the operative gives of his best and earns well, remember the selling prices are based on what

the management is paying, do *not* cut it down, because the more production obtained, the lower the overhead or dead charges in proportion.

The Human Element.

One of the most important points in light castings of sections $\frac{1}{8}$ in. or less (customers, by the way, look upon it as *the* most important) is the question of machinability; this is quite easily attained with ordinary compositions of pig-iron and without the necessity of purchasing any special brands at excessive prices, such as

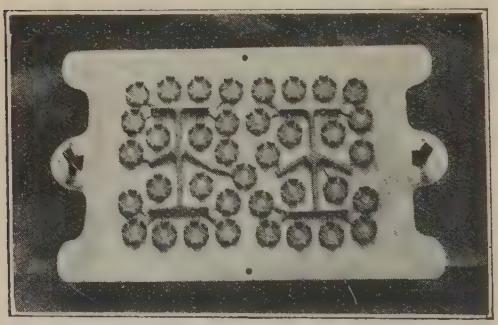


Fig. 2.—Plate-Pattern for Snap Flask Moulding.

scrap-absorbing products, which are merely high-silicon irons and are almost the last thing desirable, as slow cooling is the essential factor.

It is always desirable to have the choice of (say) three ranges in the stock yard, working preferably on a silicon basis. Strong iron of 1.25 per cent. or thereabouts; medium, which may be called the average or standard supply, with 2 to 2.5 per cent.; and soft, with about 3 per cent. Si. The first and third are for occasional use as necessity demands, the second is the general and regular standby, and if required to strengthen or tone down a proportion of one or the other is added.

Whilst strongly and emphatically recommending scientific control where possible, one must recognise and appreciate the views of small manufacturers, who say with truth that all blast-furnace pig-iron producers sell to analysis, and

Fig. 3. Showing Method of Mounting Patterns for Plate-Moulding for Doubling Production.

these in most cases are reliable. It is a fact that standard brands can be depended upon to be quite regular, and the cost of installing and maintaining a laboratory, to a foundry buying from 10 to 20 trucks of pig-iron *per year*, would

be out of all proportion to the selling price obtainable, but where quantity warrants it is folly not to incorporate the desirable adjunct. Pig-iron, fuel, ganister, limestone and all purchases should be rigidly and regularly analysed

Fig. 4.—Typical Plaster of Paris Patterns.

and controlled, as should all products, to ensure that uniformity, which is the essence of success. By normal everyday practice it is possible to obtain a definite and regular product from the cupola.

According to Moldenke, "when the fuel bed in the cupola is allowed to sink too low during a heat, the metal is forced to melt too close to the tuyeres, with the resulting oxidation of not only the silicon, manganese and carbon, but also of much iron. This iron oxide attacks the lining, and with ash and sand present from the coke and pig-iron charges gives a copious 'foaming' slag. The blast takes this upward and sends it out of the charging door. If the blast is shut off this slag drops again and floods the windbox through the tuyeres, making a nasty mess of it. Hence the supreme importance of melting in the proper position of the cupola,

FIG. 5 SHOWS TWO CASTINGS, ONE DEFECTIVE THROUGH MAL-PROPORTIONED RUNNERS, AND THE OTHER SOUND AFTER ENLARGING THE RUNNER.

above the tuyeres. It is the basis of successful cupola practice."

Light castings require a hot fluid metal and should be left in the mould until thoroughly cool; if the combined carbon in a casting runs below 0.6 per cent., machining is reasonably easy, if 1 per cent., machining becomes difficult, and at 1.5 per cent. it becomes impossible, as ordinarily understood.

First and foremost, one must decide on a standard size of box, whether for snap-flask or machine, say 16 in. by 12 in., together with a half-size (12 in. by 8 in.), which, when two are fastened together, conform to standard. Obviously, it is not always possible to keep to

this standard for machine work, but almost without exception, it is maintained for snap flasks, or what is known in foundry parlance as "stump moulding." Having thus decided, then the question is: how many patterns can be

Fig. 6 shows the Style of Detail Castings Left to Smallness of Risers.

accommodated with due allowance for runners and down gates?

The jobbing foundry envies the concern which has a profitable output in a line of product worked by mass production and no change of

mixture, yet such concerns envy the skill necessary in a jobbing foundry where mere automatons have little or no space, every pattern differing and requiring its own consideration for production and mixing according to section. It is

Fig. 7.—Here the Defect shown in Fig. 6 has been Eliminated by Heavier Risers.

nothing unusual to have five or six different mixtures per day, ranging from light electrical work of $\frac{1}{8}$-in. section, or even less, to machinery or die castings up to 8 in. and involving uneven sections.

Cardinal principles for jobbing foundry practice are:—(1) Aim to produce only high-grade work; (2) sell at the top figure the market will bear, this involving good salesmanship; and (3) ascertain costs to the smallest necessary detail. The cost system should show in the simplest and quickest way, just what is needed to get reliable results.

When the administrative head of an iron foundry receives an inquiry for his products, he is faced with a chart, simple in its way, but which summarises a store of information, the concentrated essence of experience, and this chart (Table 1) should be noted carefully, because it forms the whole basis of the structure, variable and invariable, upon which the success or non-success of the business depends.

This does not mean that the formula is followed by everybody in this form; larger concerns have a more elaborate, detailed, and many times sub-divided system (each one employing a staff) which, however, is boiled down to a percentage on production, and therefore amounts to the same thing. Others work by rule of thumb, producing and selling with little, if any, idea of cause and effect, as long as they are on the right side at the end of the year, and if, as often happens, in slump or bad times, they not only do not show a profit, but a substantial loss, they wonder why.

The chart (Table 1) needs constant check and supervision due to possible fluctuations in prices of raw materials, and consequently in finished products.

The iron as pig costs 70s. per ton delivered at works, but as good machinery scrap can be purchased for a considerably lower figure, and the production can safely utilise a large proportion, depending on the particular job, one can thus enter a reduced figure on the chart. This does not apply to malleable iron.

Waste or melting losses can be calculated and substantiated by trial, in the larger concerns daily by difference in the weight charged, resulting castings, sprues and runners; and in smaller

foundries by actual periodical test, and checked by weekly or monthly returns. This shows the necessity of keeping up-to-date records, without which hopeless confusion prevails.

TABLE I.

Materials. £ s. d.	*Per Ton.*	*Labour Wages.* £ s. d.
3 0 0	Iron (50/50, Pig at 70s., Scrap at 50s.)	
0 3 0	Waste, 5 per cent. (melting losses)	
	Making (actual) 7 lbs. : 3d. : : 112 = $\frac{336}{7}$ =	4 0 0
	Cupola, 20 tons p.w., 2 men, £9	0 9 0
0 10 9	Coke (including bed), 43s. per ton, 5 cwts. to 1 ton of iron)	
0 10 0	S. T. W. (Limestone, ganister, bricks, lining)	
	Fettling and sand-blasting (Tonnage-wages)	0 10 0
	Cores (varying)	0 5 0
4 3 9		5 4 0
	E.C's 100 per cent. on productive wages ..	5 4 0
	Materials	4 3 9
	Prime cost	14 11 9
	Profit, 20 per cent. ..	2 18 4
		17 10 1
	Add, carriage	
	Agent's Commission ..	
	Discount	
	Selling price	

Labour Charges.

Every concern has a system of rating, piece work or day work, invariably based on tonnage,

a standard price for a standard mould, varying according to its nature, whether plain, intricate, cored, light or heavy. If 3d. is the price per mould, and the weight of the castings 4 lbs., a simple calculation :—

$$4 : 3 :: 112 = \frac{336}{4} = 84\text{d.}$$

will show this to be 7s. per cwt., £7 per ton. Should the castings weigh 8 lbs., the price will be proportionate, $8 : 3 :: 112 = \frac{336}{8} = 3\text{s. } 6\text{d.}$ per cwt., £3 10s. per ton, hence the difference between the selling price of large or small, heavy or light castings.

Fuel.

One has to know the total amount of coke consumed per ton of iron for the calculation. Assuming 5 cwts. per ton at 43s. per ton, it gives 10s. 9d. per ton of iron; this is, obviously, a variable item, either for price or quantity.

The next item (S. T. W.) calls for detailed explanation; sand, tear and wear actually means all the essentials which cannot be allocated to one specific charge, but are necessary for the working of the system. It includes cupola bricks, ganister for ramming, limestone, sand, coal dust, etc. Wear and tear can be reckoned for any period on tonnage, in so far as they relate to casting materials.

Fettling, or dressing, is self-explanatory, and easily arrived at by dividing tonnage by wages.

Cores may be a serious proportion of the job, as, for example, in motor-cylinder manufacture, or only an insignificant item. It will be found, almost without exception, that each one calls for separate consideration and calculation.

It will now be seen that the system has arrived at a stage when those using it can satisfy themselves what the materials and labour are to cost. The next item is perhaps the most important in the whole procedure, that is, E.C.'s or overheads, as it embodies rent, rates, taxes, insur-

ance, salaries, non-productive wages such as patternmakers, warehouse, office, maintenance, repairs and so on, and is usually based on tonnage produced, or as a percentage on productive wages. Particular attention is called to this,

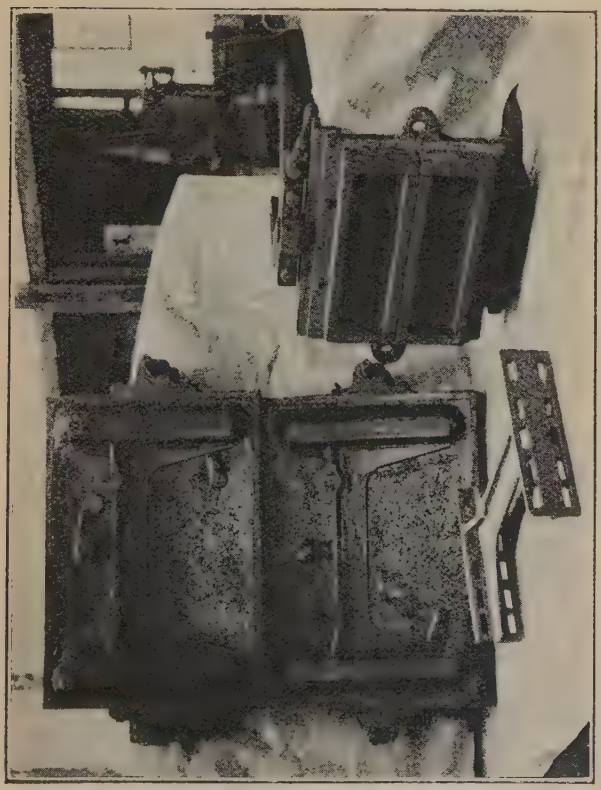


Fig. 8 Illustrates a Core Box for Machine Production.

because on their proper understanding and function so much depends.

One should satisfy oneself, therefore, that for every £1 spent on "productive" wages a similar amount is necessary to cover overheads, so one

adds 100 per cent. to the former, plus the materials, and arrives at the prime cost. The management has now to decide what margin of profit its commodity will stand. If one was dealing in gold, platinum or some of the rare metals, maybe 1 or 2 per cent. would provide ample remuneration, but a cheaper article, such as

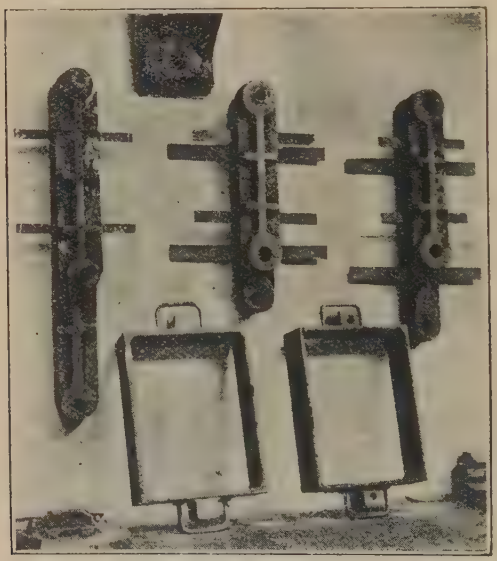


FIG. 9 SHOWS A METHOD OF JIG-DRILLING FROM HOLES FOR MOULDING BOXES RANGING FROM 11- TO 30-IN. CENTRES.

iron, necessarily requires considerably more to cover all the possible risks inherent to the business, and one decides on (say) 20 per cent.

An inquiry may call for the goods to be packed and delivered English port, or a distance of 100 railway miles, and this extra is added, as is also commission to the selling agents, and thus one arrives at the price which *should* be obtained for the goods.

Patternmaking.

A blueprint, from the original drawing, is usually supplied to the patternmaker; this entails draughtsmanship of the first order, a highly-skilled occupation, as so much depends upon correct dimensions, proportion, section and coring. The patternmaker must know whether the pattern to be made is for production, or a master for making working patterns, as due allowance must be given for contraction in

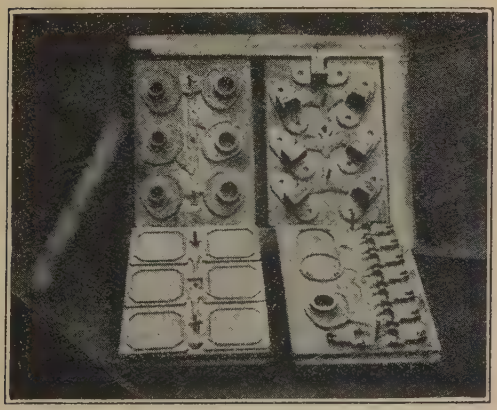


FIG. 10.—SHOWING MEANS ADOPTED FOR MAKING TWO SMALL PLATES INTO ONE OF STANDARD SIZE.

aluminium, gun-metal or iron. A pattern metal, consisting of an alloy cited by THE FOUNDRY TRADE JOURNAL, which is almost non-contracting, consists of 40 per cent. Sn, 17 per cent. Sb, 40 per cent. Pb, 1 per cent. Cu and 2 per cent. Bi. Aluminium patterns are particularly useful for operatives, by virtue of lightness; they may considerably increase output, through workers not being fatigued by continual lifting of a heavy spray of patterns. It should be under-

stood that a man will make upwards of 70 moulds per day, which he also has to cast and knock out.

From the master pattern one now proceeds to make the necessary working patterns, accord-

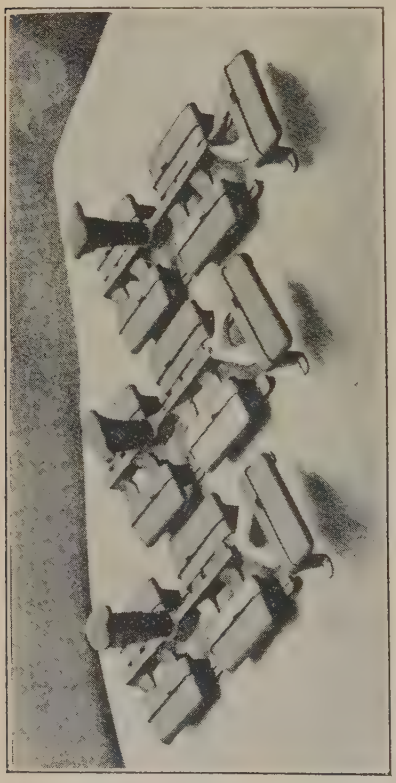


Fig. 11 shows a Case where the Risers and Runners are Heavier than the actual Castings, of which 15 weigh 2 lbs. 12½ ozs., whilst the Runners are 2 lbs. 15½ ozs.

ing to the number of castings required and the method of production—whether for plate-moulding, plaster-of-paris oddside, or single working. Quite a number of factors enter into consideration at this point, as, for instance, quantity,

which is the most important, for on this hinges the whole procedure. Assuming that some thousands of castings are quoted for and ordered, the management has then to decide how they are to produce economically. Obviously

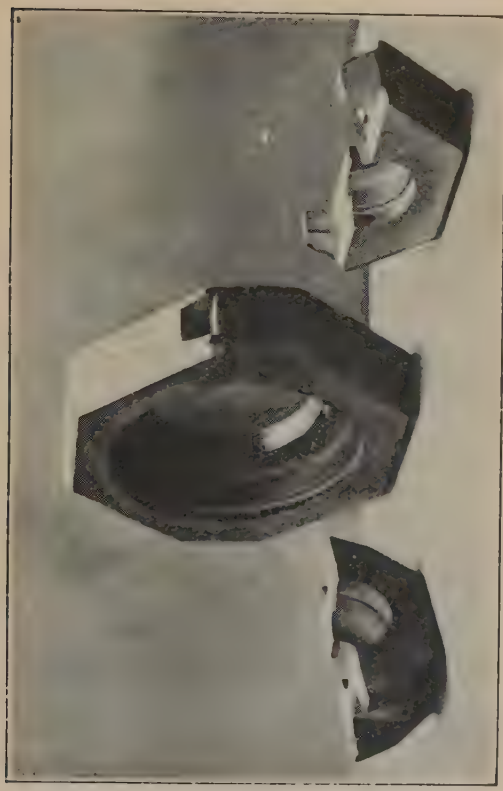


Fig. 12A showing the Core Stocks. Note the Threads.

a uniform and consistently regular article is required for engineering, electrical, or similarly important trades, where expensive jigs are supplied to the operatives; these men are probably paid on piecework rates and rely upon consistent

castings no limit whatever that. Obviously any variation in the dimension, machinability, section, etc., profoundly affects the earning capacity of the operative, whilst production in the shop reflects itself correspondingly and in

FIG. 12B SHOWS THE CORES CARRYING THE THREADS.

a very short time returns to the source, with far-reaching consequences.

Thus the author in such conditions would decide on plate-patterns such as are illustrated in Figs. 1 and 3. These may appear expensive,

but, in view of the nature of the work, unavoidable, and first cast is final. In case of necessity, production can be doubled by the method indicated in Fig. 3.

Here a further stage of metal-patternmaking

FIG. 12C.—THE FINISHED CASTINGS.

enters, again a highly-skilled occupation, which requires precision, judgment, a sound knowledge of foundry practice and the human element, so as to make production as near fool-proof as possible. The metal patternmaker must

know where to place the ridges or runners, risers, spinners if necessary, and also how many patterns can be conveniently and economically accommodated; whether for snap-flasks, with or without binders, or in iron moulding boxes, where there is less fear of the molten metal bursting through the sand, in fact, every consideration which gives maximum production with minimum loss or waste must be envisaged. Being satisfied by trial that the product conforms to all requirements, specification, weight, cost and the like, one is ready to proceed with the millions desired and never attained.

Alternately, a cheaper, but none the less useful form of production, is by plaster of Paris moulds. As many metal patterns and ridges as possible are laid true—an essential—on a sand mould, parting powder is shaken well over, and a covering of oil is carefully brushed on to prevent sticking. A rigid box part about 2 to 3 in. deep is placed over, plaster of Paris is run in and allowed to set, which it does very quickly. At a suitable moment, and when in the plastic state, it is levelled off, turned over, and the patterns and ridges extracted. The reason and value of the oil-covering will be apparent, for without this the mould would crumble, whereas each pattern is lifted out cleanly and a perfect impression and joint are left. When the mould is thoroughly dried, the patterns and ridges are replaced, soldered up, finishing touches applied, and it is ready for production. Such a pattern is shown in Fig. 4.

The importance of correct gates and runners has already been emphasised, but certainly not too strongly, as this is a phase upon which too much attention cannot be bestowed, as every single job requires its own consideration whether small or large. Fig. 5 shows a case where too much runner gate has been provided—result, dirty castings—and at its side a second casting corrected to proper proportions, enabling the down gate to be filled up with ample running space, so that any scum or loose sand may rise to top. Fig. 6 is interesting as showing two

sprays of defective castings due to insufficient metal in the risers, the good ones with deep risers having been knocked off. This condition is shown corrected in Fig. 7. Fig. 8 shows the moulds and core box for machine production, whilst Fig. 9 shows a method of jig-drilling for moulding-box locating pins which are loose bushes in hardened steel, and have wrought-iron stays. The arrangement covers 11, 12, 14, 16, 20 and 30 in. centres.

Fig. 10 shows four half-moulds 12 in. by 8 in., and how they are fastened together to make a standard-sized mould. Fig. 11 illustrates a full mould consisting of three sprays and 15 castings, weighing 2 lbs. 12½ ozs. The gates and runners weigh 2 lbs. 15½ ozs., a total weight of 5¾ lbs., the sprues and runners being actually 7 per cent. more than the castings.

Fig. 12 A, B, C clearly shows how a complicated pattern can be made into a simplified moulding operation. It is an interesting innovation and is worth detailed consideration. It will be seen that the moulding operation is simplified and an apparently intricate job resolves itself into quite an ordinary proposition under modern conditions. The sand used is red and black in approximately equal proportions mixed with resin and dried at about 200 deg. C.

Sea sand is often unsuitable in foundries where casting is carried out only once daily, and consequently moulds are cored, closed and stand over until the latter part of the day. The moisture absorbed by sea-sand cores from the green-sand moulds, causes sagging and distortion. Plain finger cores for hubs quite often sag seriously. Where extra strength is required for threads, a little more red sand can advantageously be added. Core stocks are made in iron, faced and threaded according to size, due allowance being provided for contraction, and the finished product ready for use comes straight from the foundry, after cleaning and fettling. If one cares to run over the threads with a chaser to give the appearance of a machined product, and secure a higher selling price, so much the better.

West Riding of Yorkshire Branch.

MODERN PRACTICE IN CAST-IRON TESTING.

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During recent years a great deal of attention has been devoted to the question of the testing of cast iron, concurrent with the general renaissance in iron-foundry practice which commenced during the war. British foundrymen have played a not inconsiderable part in this wave of development, and proof of the study they have given to the subject is found in the new B.E.S.A. (now B.S.I.) specifications, particularly that for general grey-iron castings, issued in 1928. Although a good many of the larger testing authorities still adhere to old methods, and although the specification is open to criticism in various matters of detail, there is reason to believe that it is attracting more serious attention from progressive ironfounders and engineers than when it was first issued.

But whether or not this specification ever becomes generally adopted, even its most ardent advocates cannot pretend that it achieves finality and settles once for all the difficult question of testing, which must inevitably become more complex with every step towards improvement and specialisation in foundry practice. Nor can it be claimed, without careful comparison, that the British specification is necessarily the only or the most satisfactory solution of the testing problem at the present time. It should therefore be a matter of more than ordinary interest to the British foundryman to inquire into the methods of testing which are adopted at the present time in other industrial countries, to examine them critically and compare them with his own standard procedure. Such an examination will show that there are several different methods of approach to the testing problem for

which strong arguments can be put forward, and even if all other methods are found wanting by comparison with our own practice, the British foundryman will at least have increased his own confidence in the B.E.S.A. (B.S.I.) specification.

In this Paper it is therefore proposed to undertake a brief survey of the testing methods in use in this and other countries, notably France, Germany and America, and to see what lessons can be learnt from a critical comparison. It is important to point out at the outset that the methods described here are not necessarily methods which are universally employed in the countries referred to, any more than the B.E.S.A. (B.S.I.) bars are universally employed in this country; rather should the methods be regarded as representative of the practice of the more progressive testing authorities and as indicating the consensus of enlightened foundry opinion in the country concerned.

British Standards.

To commence the survey at home, the traditional British test for cast iron is, of course, the transverse test. This has been employed from the earliest days of industrial expansion; it was the obvious form of test in days when cast iron was commonly used for beams, and its long life has been largely due to the simplicity of the test and of the machine employed. The traditional British test-bars are the 1-in. square section tested over a span of 12 in. and the 2-in. by 1-in. rectangular bar tested over 36 in. Both are still used by important bodies, the larger bar being, in fact, standardised for cast-iron pipes. As a rule, these bars have been separately cast.

The B.E.S.A. (B.S.I.) specification for general grey-iron castings issued in 1928 allows for transverse and/or tensile tests at the discretion of the purchaser, and empowers him to have the test-bars cast on where practicable, though the arrangement of the mould is left to the discretion of the foundryman. This specification, so far as the author is aware, was the first officially

TABLE I.—*B.E.S.A. (B.S.I.) Specifications.*

Key.	Thickness of casting.	Transverse bar.			Tensile test.		
		Cast dia.	Modulus of rupture.		Turned dia.	Tensile strength.	
			Grade A.	Grade C.		Grade A.	Grade C.
S	< $\frac{3}{4}$	0.875	24.2	19.6	0.564	12	10
M	$\frac{3}{4}$—2	1.2	23.1	18.9	0.798	11	9
L	> 2	2.2	19.2	17.2	1.785	10	9

promulgated specification in which the cross-section of the test-bar was made dependent on the dimensions of the casting it was intended to represent. There are three standard round bars, S,M,L, corresponding to the ranges of "mean cross-sectional thickness" indicated in Table I. The bars are subjected to transverse test without machining, and minimum values for the breaking load and deflection are both specified for two grades of iron: Grade A and Grade C. The tensile test-bars are machined from the broken ends of the transverse bars, to dimensions shown in the table, and the specified tensile strength varies with the size of test-bar and grade of iron.

It will be noted that this specification recognises three mechanical qualifications for cast iron; its tensile strength, its transverse strength and its deflection under transverse loading. It also recognises in principle the effect of the rate of cooling on the mechanical properties, by the adoption of three standard bars, though it does not profess to carry this recognition to its logical conclusion, for according to Pearce the $\frac{7}{8}$-in. bar was chosen as the smallest which it is satisfactory to cast, the 2.2-in. bar as the largest it is easy to test, and the 1.2-in. bar in order to fall in line with the agreement reached by the International Association for Testing Materials in 1913.

American Standards.

In America the traditional test has again been the transverse test, and there has existed the same diversity of test-bars as in this country. The 1-in. square bar tested over 12 in., and the 2-in. by 1-in. bar tested over 24 in., were among the most popular until the famous "Arbitration Bar," $1\frac{1}{4}$-in. dia., tested over a 12-in. span, was introduced by Walter Wood in 1903. This arbitration bar has recently been modified as a step towards international agreement and has now the same dimensions as the British mediuni test-bar: 1.2 in. dia. tested over a span of 18 in.

The bar is cast separately in a vertical dry-sand mould. The transverse test is carried out on the rough bar, both load and deflection being specified. Tensile bars are prepared from the ends of the transverse bar in much the same way as the British, but the form of tensile pieces is quite different, being considerably shorter, as indicated in Fig. 1. Table II shows the specified strengths and deflections. It will be noticed that two grades of iron are recognised; ordinary and high-test. It will also be seen that

TABLE II—*American Standard Tests for Cast Iron (Arbitration Bar).*

	Class of Casting.		
Ordinary Grade—	Light.	Medium.	Heavy.
Transverse Load lbs.	1,500	1,750	2,000
Deflection .. in.	0.20	0.20	0.20
Tensile strength lbs./sq. in.	18,000	21,000	24,000
High-Test—			All Classes.
Transverse load .. .. .. lbs.			2,250
Deflection .. .. in.			0.24
Tensile strength .. .. lbs./sq. in.			28,000

Classification.

Light castings: having any section $< \frac{1}{2}$ in. thick.
Heavy castings: having no section < 2 in. thick.
Medium castings: not included in either above.

some attempt is made to recognise the principle of the rate of cooling, though in quite a different manner from our own specification. Instead of using different test-bars for different thicknesses of casting, a single test-bar is used with different test requirements according to the thickness represented. Owing to these differences it is not easy to compare the British and American tests at all closely, but it will be noticed that the American deflection requirements are considerably greater than those for the corresponding British bar.

German Tests.

The traditional German test-bar is a round bar 1.2-in. dia. subjected to transverse test over

a length of 24 in. between supports. This bar has almost the same section as the American bar but is considerably longer. It is cast in a separate mould and is tested in the rough, both breaking load and deflection being specified.

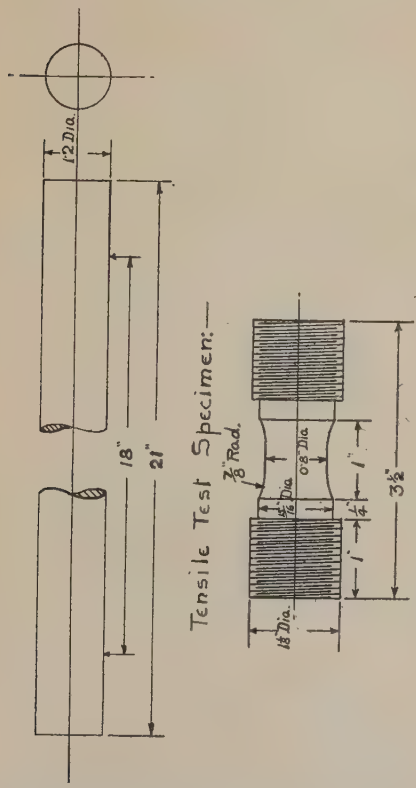
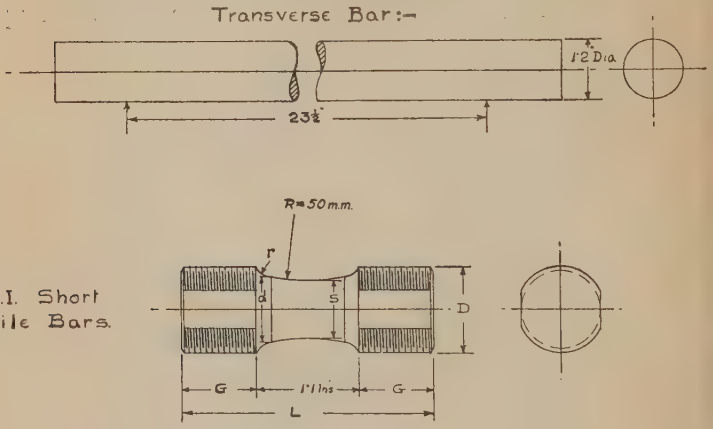


Fig. 1.—The American Standard Tests for Cast Iron. (The upper sketch is the Arbitration Bar and the lower the tensile test-piece.)

This bar is still firmly established as the standard, and no serious attempt seems to have been made to recognise the mass effect so far as the transverse test is concerned.

But this principle is clearly recognised in the specification for tensile tests which has been

advocated recently by the V.D.I. and other German testing authorities. The bars for these tensile tests are short and their diameter is specified according to the mean wall thickness



S		Dimensions in m m				
ins	m.m.	D	G	d	r	L
·24	6	10	12	7	1	52
·32	8	12	15	9	1·5	58
·39	10	16	19	13	1·5	66
·47	12	18	22	14	1·5	72
·55	14	22	26	17	2	80
·67	17	24	29	19	2	86
·79	20	27	32	22	2	92
·90	23	33	40	26	3	108
1·06	27	39	47	32	3	122
1·26	32	45	54	37	4	136
1·50	38	52	62	43	4	162

FIG. 2.—THE GERMAN OFFICIAL STANDARD TEST-PIECE DIMENSIONS.

of the casting, the bars being either cast-on to the casting or taken from a sampling flange in such a way that the root diameter of the screwed ends is equal to the representative casting thickness. At present the range of sizes is rather

numerous, as will be seen from Fig. 2, but it is apparently intended to reduce this number later if it is found desirable.

The general shape of the tensile test-pieces will be seen from Fig. 3, which shows the largest and smallest and an intermediate size. They are essentially short test-pieces and so correspond more nearly to American than British

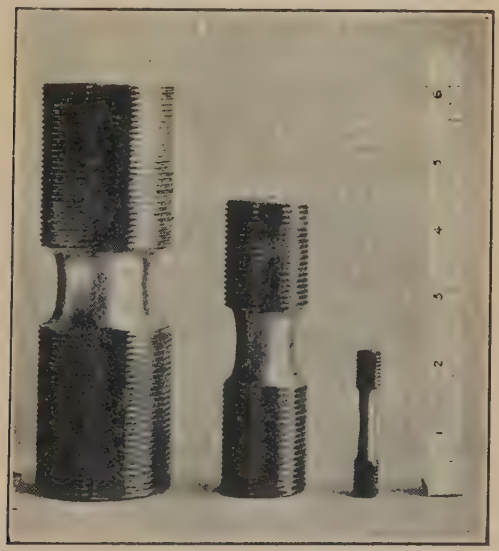


FIG. 3.—THE LARGEST AND SMALLEST AND AN INTERMEDIATE SIZE OF THE GERMAN OFFICIAL TENSILE STANDARDS.

practice, but they differ from the American tensile bar in having no parallel gauge length whatever, the central portion being machined to a circular profile.

In addition to the transverse and tensile tests, which seem to be generally accepted all over Germany, a number of other forms of tests have been proposed by testing and foundry authorities

in various parts of the country. These tests include the ordinary Brinell ball-hardness test, using a 10-mm. ball and a load of 3,000 kg.,

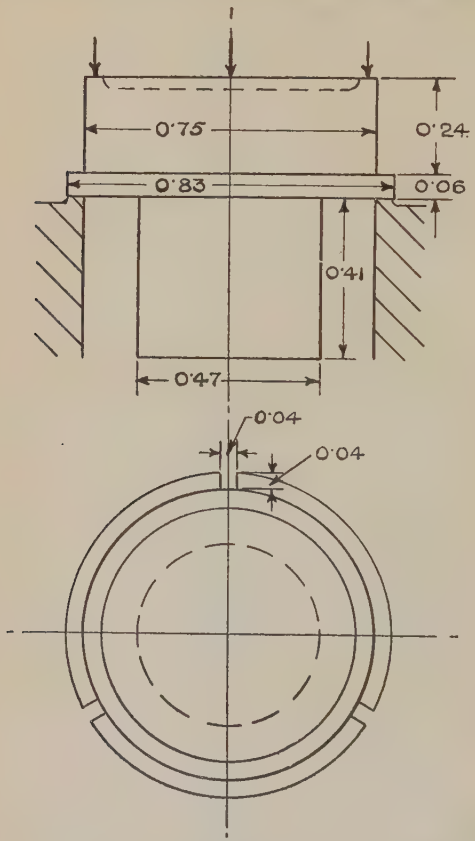


Fig. 4.—The Sipp-Rudeloff Shear Test Specimen.

the Charpy impact test on specimens 8 by 10 by 80-mm. span, either with or without notch, taken from fractured bend test-bars, and a number of suggested forms of shearing test.

These shearing tests are of more than ordinary interest, because there is a very considerable body of instructed opinion on the Continent which regards the shear test as more valuable and informative than the tensile test on cast iron, a point of view which is little known and still less appreciated in this country. The forms of shear test, more closely associated with German practice, are punch tests, in which the central core is punched out of a turned specimen or disc. The form of specimen has been the subject of much discussion and research, for which credit is mainly due to Karl Sipp and Rudeloff.

A test-piece, of the type proposed by Sipp in 1920, is shown in Fig. 4. It was intended that it should be machined from a special boss on the casting. The collar rests on a hardened shearing ring, and pressure is applied on the upper face until the collar is sheared through. As an outcome of a considerable research, Rudeloff modified this specimen, as shown in Fig. 5, so that the flange was only 0.06 in. thick and 0.04 in. wide, with three radial saw-cuts to reduce the chance of parasitic stresses. Later Rudeloff has proposed to replace this rather elaborate specimen by a plain turned disc, about 1 in. dia. and $\frac{1}{10}$ in. thick, with three radial saw-cuts, as indicated in Fig. 5. At the present time attention seems to have been directed rather away from the punch test to the pin-shear test, which consists in shearing through a cylindrical rod usually obtained by trepanning the casting. This is an adaptation of the Frémont shear test, to which reference is made below, but with larger-sized pins than are used in France. An idea of the sizes of the Sipp-Rudeloff and Rudeloff specimens is given in Fig. 6, where they are shown with a standard 1-in. gauge.

French Tests.

France appears to have been the original home of the transverse test, for the so-called Monge test was in use as early as 1790 at the famous Creusot Foundry, being applied to a

cantilever of $3\frac{1}{4}$-in. sq. section, 20 in. long. Eventually the Monge tests were superseded in France by tensile tests and impact tests, the tensile tests being commonly made on bars $\frac{5}{8}$ in.

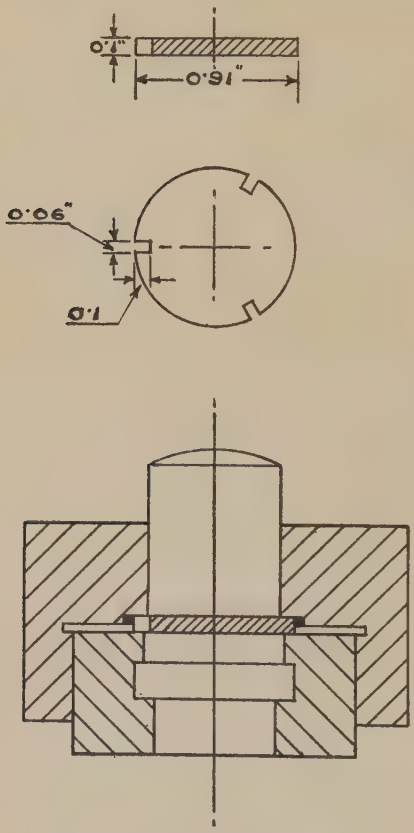


Fig. 5.—The Rudeloff Disc.

or 1 in. dia. The impact test was carried out on a bar $1\frac{1}{2}$-in. sq. section, $6\frac{1}{4}$ in. between supports, a load of $26\frac{1}{2}$ lbs. being dropped on to it from successively greater heights until the bar

failed or the particular specification was satisfied. Both these tests were normally made on separately cast bars. The Charpy form of impact test was also in considerable use on bars 0.4 in. sq., with just over 2 in. between supports.

In recent years there has been in France a very significant reaction against these tensile and impact tests, and a movement to replace them by

FIG. 6.—SHOWING THE SIPP AND SIPP-RUDELOFF SPECIMENS AT THE SIDE OF A 1-IN. GAUGE.

transverse and shear tests made on test-pieces of a size which could be taken from the casting itself, and by Brinell hardness tests. This has been an essentially French development, and has been due notably to the work and advocacy of Frémont, Portevin, Ronceray, le Thomas and Guillery.

In 1912 Frémont introduced his famous transverse and shear tests. The transverse specimen was about 0.32 by 0.4 in. section, tested over a

span of 1.2 in. The shear specimen was $\frac{1}{2}$ sq. in. in section, either square or circular, and about 0.8 in. long. The circular specimen was cut from the casting under test by means of a hollow drill or trepanning tool, released by means of a special double sleeve with an eccentric action, and tested without subsequent machining in a shearing machine of the lever type, tests being made every $\frac{1}{8}$ in. along the

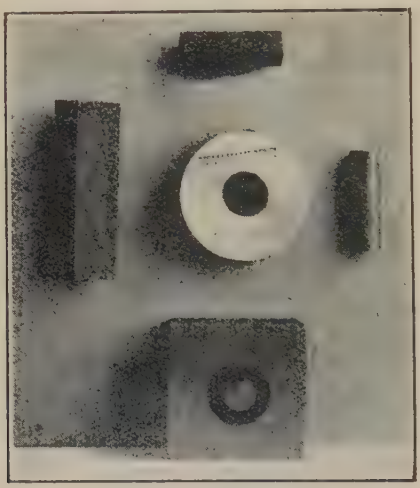


FIG. 7.—THE FRÉMONT SPECIMENS SHOWN WITH A 1-IN. GAUGE FOR SIZE COMPARISON.

specimen until it became too short to hold. The Frémont specimens are shown in Fig. 7, with a 1-in. gauge for comparison.

The original apparatus used by Frémont was rather crude, and subsequent designs have been considerably improved, but the size of test-pieces and general methods of test remain unaltered. One of the best-known machines employed at the present time is the Guillery machine, which is essentially a ball hardness-testing machine, with

attachments to adapt it for the Frémont transverse and Frémont shear tests. One of the arguments in favour of the French system of testing is the fact that a single machine can be employed to carry out all three forms of test.

Specifications based on the Frémont tests have been adopted by the French Marine and important railway and other authorities in France and Spain. Details have been published by le Thomas and Bois of a complete specification of this kind, which will give a good idea of recent French practice. Tests are specified up to five in number, depending on the grade and size of casting. Of these the first two are shear tests, the next one transverse and any remainder shear tests, with the provision that if necessary, through lack of equipment, an equal number of compressive or transverse tests may be accepted in place of the shear tests. The requirements for various grades of iron are shown in Table III. It will be realised that since the test-pieces are taken from representative points on the casting itself the question of mass effect is already involved and does not arise as a separate problem.

Choice of Testing Methods.

The ideal test for any casting is obviously one which reproduces the essential conditions of service. For example, a valve body is best tested under hydraulic pressure, a piston ring by its elastic behaviour under strain and a cast-iron wheel by its resistance to shock. This procedure is, however, only applicable in a few special cases, and even then it is difficult to standardise sufficiently for routine acceptance tests. All other forms of test are so-called " substitution " tests, in which it is presumed to infer the suitability of a casting for its work from the results of tests of certain accepted types which can be standardised. Which of these forms is the most informative depends upon the nature of the material and the purpose for which it is intended, and it does not follow that the same form of test will be equally satisfactory for every type of casting. Certain types have already their own specifications and methods of testing, and

TABLE III.—*French Specification Based on Frémont Tests.*

Class of cast iron.	Shear, tons per sq. in.	Transverse tests.		Brinell No.	Compression, tons per sq. in.
		Load, lbs.	Deflection, in.		
Extra strong ..	15.9	1,210	0.012	170—240	50
Strong	12.7	990	0.010	150—240	40
Ordinary	9.5	770	—	130—240	30

it will only be in keeping with modern specialist development in the foundry if this practice is extended still further. But to embark on speculations of this kind without examining the possibilities and limitations of existing test methods would serve no useful purpose.

Tests of materials can generally be divided into two classes; acceptance tests and exploratory tests. Acceptance tests are those standardised forms on which a material is accepted by a purchaser, and on account of the conditions of inspection they must be of a simple and quantitative character. Exploratory tests on the other hand are such as might well be carried out by a progressive foundry or works in the development of new mixtures, new methods of production or new classes of castings. These tests will probably include acceptance tests for reference purposes, but the most valuable information might well be derived from tests of a more special character, perhaps even devised for the particular development in hand. In comparing the various tests in use at the present time it will be well to appreciate this dual function of testing and not on the one hand to reject summarily every test which involves trouble in its preparation or on the other hand to accept without question every test which measures any specific property. In testing cast iron there are two main features of its metallurgical structure which affect the choice of tests, the constitution of the crystalline "groundmass" as the Germans call it, and the nature and arrangement of the free carbon which is the chief source of mechanical weakness. A test in which the crystalline structure is dominant is unlikely to prove of general value where mechanical strength is required, and in the same way a mechanical test may be of little value where resistance to wear or corrosion is a more important consideration. This dual character of cast iron also suggests that it would be uneconomical, in routine testing at any rate, to adopt two different forms of test whose results are both dependent on the same structural characteristic of the iron.

Incidence of Mass Effect.

If these structural characteristics presented the only problem in cast-iron test procedure there would be no more difficulty about agreement on standardisation than there is with steels. But cast iron introduces a peculiar difficulty of its own, namely, the powerful influence exercised on all mechanical properties by the rate of cooling of the iron in the mould. The problem of making proper allowance for this "mass effect" in cast iron is probably the most troublesome problem in materials testing at the present time.

As is well known, the rate of cooling in the mould effects both the crystalline structure and the distribution and condition of the graphite, and these will vary, therefore, not only between one casting and another but also between one point and another of a single casting. The cooling effect does not follow any simple general law, but is subject to many influences including the the shape as well as the mass and mean wall thickness of a casting, the type of mould and size of moulding box, the class and quality of the metal used and the casting conditions. The mass effect influences some forms of test more than others, the tensile and transverse tests being more sensitive than the Brinell and generally than the compressive test, and no general correlation has been found possible between these different tests.

In order to recognise and make allowance for the mass effect in testing, three quite different methods have been adopted in different countries. The French method is to test portions of the casting itself, the British and German idea is to test bars so cast that they are representative of the metal in the casting and the American method is to use a single standard bar and to interpret the results with a view to the mass effect.

According to the French view, the effect of the rate of cooling can only be properly recognised by sampling from various parts of the casting itself, a method which theoretically gives not

only an average test value but also an indication of heterogeneity from variations between tests. This idea does not seem, however, to be carried to its logical development in France, for in the published specifications, based on the Frémont tests, although allowance is made in the specified shear and transverse test figures for various grades of iron, no such allowance is made for different sizes of casting or different sections in a single casting.

Sampling Method.

In principle there is a strong case for the sampling method. It should give more detailed and positive information than any other method, and information which should be of direct value to the designer. Foundrymen will need no reminding that there are few castings which can be judged safely on a single test result. Moreover, the sampling method gives due credit to improvements in methods of moulding and casting, and it enables such special types as centrifugal castings to be compared with others. In practice, however, the sampling method is at some disadvantage, for only in exceptional cases can even moderate-sized test-pieces be safely extracted from a casting. The smaller the test-piece the more troublesome it is to prepare and the more is it subject to errors under test. Small test-pieces have the advantage that they enable several tests to be taken from a single complicated casting, but the number should depend on the complexity and not only on the weight of the casting as is the French practice, and moreover standardisation is difficult. The idea of special testing flanges has a good deal to recommend it, for it provides test-pieces of more convenient size, but it is still a difficult matter to standardise the location and thickness of the flanges relative to the mother casting.

This same difficulty has to be faced in connection with cast-on bars, of which the sampling flange is really a border-line type. The position of these relative to the main casting may be almost as important as their size, and unless

the conditions of casting on are carefully considered—a matter which defies standardisation—a good test-bar may not necessarily mean a good casting.

Testing Metal Properties.

This leads to a consideration of the second method of tackling the mass-effect problem; that of testing bars intended to be representative of the metal in the casting. The difficulty here lies in the choice of representative bars. Only in the case of a casting of simple shape and uniform thickness can a single test-bar fulfil this condition, and even when the casting can safely be considered homogeneous, the size of bar giving the same properties is dependent on several conditions, including the form of the casting as well as its thickness, the relative position of the bar in the mould if it is cast on, and the sizes and types of moulds if it is cast separately.

For separately-cast test-bars, Bolton has suggested that the bars should have the same ratio of volume to surface as the casting it represents, and this is probably as sound a rough general rule as can be applied. It certainly gives a better representation than the B.E.S.A. (B.S.I.) bars, which in almost every case have a more rapid cooling rate than the corresponding castings, particularly if they are separately cast.

In cases where the casting has a variable section or where its mass is so distributed as to give a variable rate of cooling, no single test-bar can be a satisfactory criterion. So far as the author is aware, the only attempt made hitherto to recognise this obvious fact without recourse to diminutive test-pieces is embodied in the V.D.I. short tensile bars, which are either cast on to various parts of the casting or taken from sampling flanges of representative thickness. But this involves rather elaborate specification and as it stands makes standardisation difficult, so that it is probably more suited to exploratory work than to acceptance testing.

The American method of using a single standard bar and requiring from it a higher test for heavier castings presupposes a general relationship between strength and section which does not exist, and it does not even face the problem of heterogeneity in the casting. The suggestion has been made from an American source that the results obtained from a single bar of this kind could be correlated with the casting itself by making additional Brinell tests on the bar and on various points of the casting and assuming that the mechanical tests can be related in terms of the Brinell numbers. It has, however, been proved by many workers that Brinell and tensile or transverse tests conform to no general relationship.

Separately-Cast Bars Advocated.

In the face of so many conflicting ideas it may seem presumptuous for one who is not in the ironfounding industry to make a suggestion on such a complex problem. When all the evidence has been sifted, however, there does seem to be a case for separately-cast test-bars, provided a sufficient number are taken to ensure proper representation of the range of cooling rates in the casting. The separately-cast bar is convenient in the foundry, it can be tested easily, it lends itself to standardisation and it facilitates comparisons between different foundries and between different mixtures and melts. If two test-bars were cast, one to represent the weakest metal and the other the thinnest section in the casting, then evidence would be available not only of the real strength of the casting at representative sections but also of the degree of homogeneity of the metal. In this way credit would be given to valuable modern developments which are reducing the sensitivity of the metal to wall thickness, and since, as Pearce has pointed out, the differences in strength between different sections are emphasised more in separately-cast bars than in bars cast close to the mass of a larger casting, the results should err, if at all, on the side of safety.

It is now proposed to examine in some detail the various forms of test which have been found useful in the testing of cast-iron bars or samples.

Tensile Test.

The value of the tensile test of cast iron has been the subject of a great deal of contention between ironfounders and engineers in different countries. The engineer instinctively bases his designs and allocates his factors of safety on the basis of tensile strength, and although it is perfectly true that he endeavours as far as possible to avoid tensile stresses in the cast parts of his machines, yet it must be admitted that the great majority of mechanical failures in cast iron are failures in tension. Moreover the tensile test is intrinsically the only form of test, apart from the rare compression test, in which one has any right to assume that the material is stressed uniformly and from which therefore one can derive any real indication of the actual stress at which failure occurs. On the other hand, the tensile test with a brittle material like cast iron is less informative than a similar test with a ductile material like steel, for it gives no yield point, no reduction of area, and no indication of any vestiges of ductility which might help to differentiate a tough from a brittle bar. It gives one figure and one figure only: the tensile strength.

In practice, moreover, there are difficulties which render the tensile test suspect among engineers and unpopular among ironfounders. The ironfounder is naturally prejudiced against a test which involves an expensive testing machine and a good deal of careful turning on each test specimen and he always feels a certain apprehension that some accidental flaw in the test-piece may give a wholly unfair idea of the intrinsic strength of his iron. Looking at the test from the mechanical standpoint, the engineer realises that there is a serious difficulty in ensuring that the test-bar shall be subjected to a truly axial pull, without which the test is quite unfair. The importance of this centreing will

be appreciated when it is pointed out that, owing to induced bending stresses, an eccentricity of the load line of 0.01 in. means an error of 10 per cent. in the result of a test on the 0.798-in. bar and 14 per cent. with the small B.E.S.A. bar. The longer the specimen and the more brittle the iron the greater will be the effect of parasitic bending on the test results. Even if the knife-edge of the testing machine is exactly in the centre-line of the straining gear, there is no assurance that the load acts exactly in the centre-line of its length unless special tackle, such as the Robertson type of grip, is employed. The short test-bars advocated in America and Germany help to reduce the effect of an oblique pull, particularly the German bars with no parallel portion, but they are no safeguard against an eccentric pull parallel to the axis of the specimen. It is to be noted in this connection that the reduction of the parallel length, which is really the only part of the bar under test, alters the character of the tensile test from a general to a purely local test across a single section; apart from this there is no possible advantage in a parallel gauge length and the shorter test-bars can be obtained much more easily from sampling flanges or cast on to the main casting. In Fig. 8 the standard American tensile bar is shown with the corresponding B.E.S.A. (B.S.I.) and V.D.I bars.

Regarding the tensile test from a detached standpoint, it would seem that since the tensile strength is of primary importance to the designer, and since no substitution test has been found from which this strength can be deduced with any confidence, it must be regarded as fundamental. Moreover, the cost of Robertson grips is small compared with the cost of the testing machine, and these will ensure fair conditions of test. These conditions are improved by the use of short test-pieces, and the latitude which these afford in the matter of casting appears to throw the balance of choice in their favour as compared with the longer bars in use in this country.

Transverse Test.

The transverse test is the oldest form of test for cast iron. It has always been deservedly popular among foundrymen and is at the present time more generally accepted than any other test. It is simple to carry out; it involves only a comparatively cheap form of testing

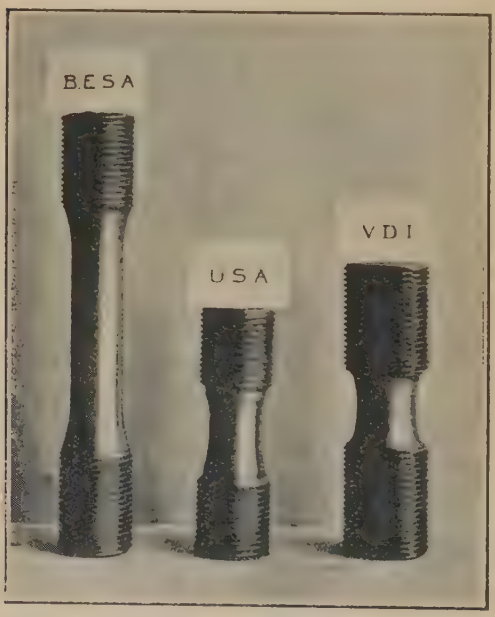


Fig. 8.—British, American and German Tensile Test-pieces Compared.

machine, and according to ordinary usage the test-bar does not require machining. The test gives two distinct though not wholly independent results; the breaking load and the maximum deflection. From the breaking load it is possible to calculate a hypothetical value for the maximum fibre stress in the bar, called the

modulus of rupture, which does not correlate at all satisfactorily with the tensile strength as found from the ordinary tensile test, being 40 to 140 per cent. greater according to the quality of the iron, but it is nevertheless some measure of its intrinsic strength. On account of its uncertain signification and possible confusion with the tensile strength, the modulus of rupture has been criticised on the Continent, but if the test is to be carried out on unmachined bars—and this possibility is one of its chief virtues—the result, being very sensitive to transverse dimensions, must be corrected for unequal cross-sections, and this correction can only be based rationally on the nominal stress, which is the modulus of rupture. The maximum deflection of a transverse bar is some measure of its capacity to deform without fracture, and therefore of its toughness. A great deal of significance is attached to the deflection measurement by some writers on the subject; it is said to "yield much important information" and to possess a "wealth of interpretation." But these writers discreetly omit to explain in what this wealth consists or in what way it can be used, except as an obvious indication of more or less brittleness. It has been suggested that the product $\frac{\text{load} \times \text{deflection}}{2}$ should be called the "resilience" and accepted as a measure of "tenacity," and Portevin claims vaguely that the "modulus of elasticity" obtained from an autographic transverse test is a valuable criterion for design. But until a good deal more is known about the processes of failure in cast iron and a good deal more evidence of "wealth of interpretation" is available, the deflection measurement is likely to stand where it has in the past as a useful rough criterion of toughness, and nothing more. If it is intended that the deflection shall be used quantitatively in any way, then the absence in specifications of any correction factors to standardise deflection figures for different diameters is an important omission.

In discussing the question of transverse tests special mention should be made of the Frémont transverse test, which is made on a small bar about $\frac{5}{16}$- by $\frac{3}{8}$-in. section with $1\frac{1}{4}$ in. between supports.

From the general standpoint it has to be admitted that in spite of the difficulty of its interpretation and of the fact that it is essentially a local test, the transverse test when properly standardised—and for proper comparisons complete standardisation is essential—does measure some complex form of strength in the bar and give some indication of its toughness or brittleness. It is therefore a useful routine test to check practice from day to day or foundry to foundry, and is a useful general acceptance test, particularly where the quality of the metal used is of more direct interest than the strength of individual castings. Small transverse bars such as those used in France are valuable for exploratory and development work, but do not inspire confidence or seem to merit the trouble of preparation for routine tests.

Shear Tests.

The shear test is not used to any considerable extent except in France, although it has been receiving serious attention in Germany for some years. Apart from the torsion test, which is seldom used except for research, there are two forms of shear test, pin tests and punch tests, which may almost be called the French and German tests respectively. The pin test consists in shearing a round or square rod transversely across its section. Attempts have been made, for simplicity in testing, to subject the pin to double shear, but it is difficult to avoid bending stresses, and almost impossible to ensure simultaneous shear on both sections, and the double shear test has found little support. The important form of pin test is the Frémont test, in which single shear is employed. For this test the specimens are either 5 mm. sq. or of diameter to give the same sectional area. According to Frémont's own idea the round specimens, about

1 in. long, are trepanned from the casting and subjected to successive shear tests at intervals of about $\frac{1}{10}$ in. along their axis. In some later machines a single test is made at the centre of the specimen in order to standardise the method of gripping, but the advantage of taking several readings on one specimen is thereby lost. It is to be noted that the test rods are small in size, and any want of homogeneity will clearly affect the reliability of a single test. It therefore becomes important to carry out numerous tests and from these to take the mean result as representative, and the consistency of the results as some measure of the homogeneity of the metal. Provided this procedure is followed there seems no more reason to reject the test because it is carried out over a small area than there is to reject the Brinell test or the results of micro-examination, which in this respect are of similar character. For purposes of investigation the small test-pieces have a clear advantage in that they can be taken from representative points of the casting itself, a procedure which would seldom be possible with large rods, although there is a proposal in Germany to adopt a shear pin of about $\frac{1}{2}$ in. dia. The objection to the Frémont trepanned rod is the difficulty and importance of obtaining an accurate and smooth cylindrical surface. Any inaccuracy of this kind affects the gripping and the conditions of stress under test, and is bound to give low results. In spite of the assurance by its advocates that a properly made trepanning tool is capable of producing perfect test-pieces, there seems to be a general agreement that subsequent machining is necessary to give reliable results.

The punch test also is essentially a test on a small specimen, which can therefore be obtained easily from the casting itself. But the machining of the Sipp-Rudeloff flanged plug, or even of the Rudeloff disc, is distinctly more troublesome than the preparation of the Frémont test-piece, and it only gives a single result, which, as already mentioned, is a matter of some

concern with small specimens. The method of holding the plug or disc in the testing machine is clearly important in order to eliminate errors, and the matrices and dies have to be standardised in every detail. The saw-cuts are introduced in order to eliminate errors due to parasitic stresses, but these must remain effective to some extent. It is also likely with the thin Rudeloff discs that penetration of the die affects the results.

There is one serious objection in principle to any form of shear test; no practical method has ever been devised—nor is one easy to conceive—which will give a uniform shearing stress across a section of any material. Every practical method of shearing introduces parasitic compressive stresses between the points of loading, and since these clearly cannot be absolutely in line—otherwise the test would become a compression test—there is necessarily some bending action, however small. Now whenever shear and bending are combined the distribution of shear stress across the section is known to be far from uniform. The ordinary text-book theory predicts that the greatest shear stress will occur at the centre of the cross-section, and will exceed the mean by 33 per cent. in the case of a circular section and by 50 per cent. in the case of a square section. When in addition to this one takes into account the small but inevitable bending action, it becomes obvious that instead of a simple uniform shearing stress across the section there is actually a system of stress which is much more complicated than that in any other form of mechanical test, and this irrespective of whether the specimen is in the form of a rod, disc or flanged plug.

When one appreciates the complex nature of the shear test and its sensitiveness to details in the condition of test, it is not difficult to understand why there is a serious lack of uniformity among results obtained by different methods in different laboratories, and why all attempts have failed to reach a satisfactory correlation either with the results of tensile and

other tests or between the results of disc and pin tests. Jolley has collated a large number of results from different sources, and finds that the ratio between shear and tensile strength is quoted at any value from 0.67 and 1.84. One French enthusiast has suggested that failure to correlate between shear and tensile results is due to intrinsic errors in the tensile test, but those who have had any experience of tensile testing will know that discrepancies of the order needing explanation are never found between tensile tests, even when no special trouble is taken to secure true axial loading. It is perhaps worthy of mention in this connection that the Czecho-Slovakian Standards Association has been carrying out an extensive independent series of researches during the past two or three years in order to evolve standard forms of test for cast iron in the light of the most recent developments, and as a result it has definitely rejected the shear test in favour of the tensile test.

Apart from any question of the practicability of the shear test, there is a very fundamental consideration which appears to have escaped notice. When any material is subjected to a system of " simple shear "—the ideal which all shear tests endeavour to approach—the stress is not by any means entirely a shear stress. On the pair of planes making 45 deg. with the planes of shear there will be no shearing stress, but tensile and compressive stresses respectively, each equal in intensity to the applied shear stress. This is a fundamental fact and applies to any material whatever. When, therefore, one applies a " simple shear " of 10 tons per sq. in., one inevitably applies at the same time—in certain directions—a tensile stress of 10 tons per sq. in. and a compressive stress of the same value. It therefore follows that the material will fail when the intensity of stress reaches the limiting value in either tension, shear or compression, whichever is the least. Now cast iron is definitely weaker in tension than in shear. To prove this one has only to carry out a torsion test, which gives a maximum stress at the skin

and a simple shear system on tangential planes. Under these conditions a cast-iron bar will without exception fail along a 45 deg. helix on the outer skin, that is along a line which is subjected to the greatest tensile and not the greatest shearing stress. It is therefore clear that even if it were possible to apply pure shear to a specimen of cast iron one would not be carrying out a shear test, but merely a complicated form of tensile test. The only form of test known to the author which does produce failure approximating to shear failure with cast iron is the compression test, and even in this case the result is complicated by intermolecular friction, and the shear stress can only be estimated approximately. If, therefore, at any later time some reliable form of shear test is standardised for cast iron, it will be necessary to realise that the results of this test do not represent the strength of the material in shear, but have actually a more direct reference to its strength in tension.

Hardness Tests.

Two forms of hardness test have been applied to cast iron; the Brinell test, in which the impression of a ball usually 10 mm. dia. under a load of 3,000 kg. is measured, and the Scleroscope test, which measures the rebound of a diamond-tipped hammer under standardised conditions. Owing to the very local character of this latter test it is generally considered unreliable when used on such a heterogeneous metal as cast iron.

The Brinell test is not so local in character, and is a very convenient and rapid form of test which can be carried out in most cases on the casting itself, particularly if a portable machine is employed. In this case tests can be made at various representative points, and any differences detected afford a useful criterion of variations in the metal in the casting. In order to obtain consistent and comparable results it is necessary to standardise the method and duration of loading, but this presents no serious difficulty.

The Brinell test is essentially different in character from the tensile test or the shear or transverse tests, for the ball impression is not dependent to any appreciable extent on the intercrystalline graphitic conditions which control the mechanical strength, but upon the constitution of the crystals themselves. It would therefore seem idle to search, as numerous investigators have done, for any close general relationship between the Brinell number and the tensile strength for example, although for a single range of irons there might appear to exist some "remarkable agreement," such as Portevin claims to have found. As a general rule, the differences between hardness numbers are much smaller than differences between tensile strengths, and the test is therefore not so sensitive to differences in the quality of irons.

The real drawback to the Brinell test as a standard form of test is the difficulty of its interpretation in terms of the mechanical properties required in service. It has little reference to mechanical strength, is often misleading as regards mechanical wear, and is often only a rough qualitative index of machineability. Its virtue is that it is a simple test which can be carried out *ad lib.*, and that it does show *differences of some kind*. Provided one does not inquire too closely into its nature, this indication of differences is a valuable means for checking consistency between individual castings of a batch or between batches cast under different conditions, and it is a very convenient means for investigating structural differences in different parts of a single casting. It would therefore appear to be a valuable form of shop test, but one which admits of standardisation for acceptance purposes only in special cases.

Impact Tests.

As already described, impact tests were used in France for many years, but the method of testing was clumsy, the results were essentially rough, and did not correlate well with other tests. In special cases, such as car wheels, the

impact test is still applied as a proof test to the casting themselves, and under these special conditions it serves an admirable purpose.

The modern forms of impact test on test-pieces are designed to measure the energy absorbed in breaking the bar when held either as a beam or a cantilever. These tests, named after Charpy and Izod respectively, were introduced for the comparison of steels, and if applied in their original form are quite unsuitable for cast iron on account of its brittleness. However, special sections of cast-iron pieces have been tried, with and without notches, and with specially light impact machines, and in this way comparative results can be obtained.

On the Continent a broken 8 by 10 mm. bend test-rod without a notch has been used in a light Charpy machine, and at Bradford Technical College the author has made tests on $\frac{3}{4}$-in. dia. bars, notched and unnotched, on a special Izod machine lent by Keighley Laboratories. The presence of a notch has little effect on the results with such a material as cast iron, and it is found that low-phosphorus and other irons whose quality is known to be good give better impact results than brittle irons, although open-grained irons have sometimes been found to give anomalously high results.

The exact significance of the impact test on cast iron is a matter of conjecture, and it is certainly not so informative as in the case of steels, for the impact fracture with cast iron is of the same inter-crystalline character as in the tensile or transverse test, while with steel the mechanism of failure is quite different under static and impact tests.

There is, however, one form of impact test which does appear at the present time to fulfil a definitely useful purpose; that is the repeated impact test. This test consists in subjecting a turned bar to transverse blows on two sides alternately. The bar is supported at both ends and a standard weight falls from a fixed height on to its mid-point, the bar rotating 180 deg. between successive blows. Kühmel in Germany

was the first to draw attention to the value of this form of test for cast iron, as the result of researches carried out under the auspices of the German committee for the testing of cast iron for railway work. He found, as would be expected, that the lighter the blows applied to the bar, the more would it stand before fracture, but he also found that the lighter the blows the greater *relative* difference was there between the number of blows required to fracture different qualities of cast iron. By using a tup weighing 5.8 lbs. with a drop of only 0.4 in. on a bar with a $\frac{1}{2}$-in. notch, he found that whereas a typical iron of 6.5 tons tensile broke after 500 blows, an iron of 10 tons tensile withstood 3,000, a 14½-ton iron 12,000, and an 18-ton iron anything from 16,000 to 30,000 blows. Hence it appeared that the repeated impact test was a much more sensitive means for distinguishing between the quality of irons than the tensile or any other static test, and that it should be invaluable as a test for exploratory purposes in the development of high-grade and alloy irons. The B.C.I.R.A. has since made tests of its own, using a 4.8-lb. tup with a drop of 1.2 in. on a 15 mm. grooved bar, and the Bradford Technical College is using a 2-lb. tup with a drop of 3 in. on to a $\frac{1}{2}$-in. turned bar without notch. In both cases it has been confirmed that better quality irons show up to much greater advantage than under static tests. This form of test is still in the exploratory stage, but it is certainly one of which one may reasonably expect to hear more in the future as a criterion of that property which is known rather vaguely as "toughness."

In concluding, the author wishes to record his sincere thanks to Mr. H. F. Poole, of the Keighley Laboratories, for placing at his disposal much valuable information regarding specifications and forms of test in use in different countries. He also appreciates the help he has received from Mr. C. Nichols in the preparation of specimens and exhibits and in all practical testing work.

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